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(Selected Articles)

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ALUMINUM ALLOYS ON LARGE COMMERCIAL AIRCRAFT

Zhao Yingtao

Civilian aircraft life generally extends to 60,000 flight hours. This type of superior performance, besides requiring excellent flight equipment and efficient structural design, also involves the adoption of a series of measures guaranteeing structural materials used. Structural materials used--at the same time as satisfying static strength test requirements--must also, under ordinary environmental as well as corrosion media conditions, possess excellent fatigue and breaking resistance as well as the ability to resist the expansion of cracks and other similar overall characteristics.

On the basis of analysis, the selection of materials for civilian aircraft obeys the principles below:

1. Should satisfy design performance requirements--among these include mechanical performance and corrosion performance;
2. Should satisfy airworthiness requirements;
3. Economics must be good;
4. As much as possible, reduce trademarks and specifications of materials used for ease of management;
5. Consider questions of familiarity and reliability associated with new materials, not pursuing the cutting edge in a one-sided manner.

Materials used in modern civilian aircraft structures still are primarily aluminum alloys. On the basis of statistics,

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

aluminum alloys are capable of accounting for 74.5% of the total amount of civilian aircraft structures. This is because aluminum alloys not only have relatively good specific strengths and specific rigidities. Moreover, their malleability is also good. They have a long period of utilization experience, and form a complete set of familiar production technologies and equipment.

This article does a simple analysis of a number of characteristics associated with the utilization of structural members in civilian aircraft selected to be aluminum alloys.

I. USE OF INFLECTION STRUCTURAL MATERIALS TO REPLACE EXTRUSION STRUCTURAL MATERIALS

Civilian aircraft fuselages adopt semi-hard shell type structures. Structural arrangements are well-proportioned, light and agile, and large amounts of the skeletal structural members opt for the use of inflection members. There is very little use of forged or extruded members. Cast members are almost never seen. This type of fuselage structure, although it looks to be relatively thin, is, however, proven through various types of tests and use on air routes. Fuselage structures possess such strong points as safety, reliability, light weight, simple manufacturing technology, good economic characteristics, and so on. The typical fuselage long purlin cross section is hat shaped, and the bulkhead edge pieces are mostly Z shaped types of materials. The great majority of these structural materials are formed by bending of 7075-T6 thin plates.

A great many extrusion members associated with alloys which are capable of being strengthened by heat processing all have extrusion effects. After going through one iteration of extrusion, structural material vertical direction strengths are raised somewhat. Because of this, on very many aircraft, utilization is made of nothing else than this type of extrusion

member characteristic, using extrusion structural materials to act as long purlins or edge pieces. The strengths of inflection of structural materials utilized in a certain number of civilian aircraft are capable, at most, of only reaching performance associated with thin plates--much lower than extrusion structural materials. From standard handbooks, at the same thickness (6.3mm or less), comparing 7075-T6 structural material and aluminum wrapping plate, it is possible to see that the structural material tensile strength is 538 MPa, and the yielding strength is 483 MPa. However, the tensile strength of the plate material is only 524 MPa, and the yielding strength is only 448 MPa. This is due to the fact that, in structural material standard values, there is still no consideration given to extrusion effects. Otherwise, they would be somewhat higher.

Inflection structural materials, although their performance is somewhat off the mark, are, however, under conditions where they satisfy requirements for structural strength, still capable of greatly reducing structural weight and costs--in conjunction with this, reducing the amount of aircraft processing.

II. USING 7075 AND 2024 TO ACT AS MAIN STRUCTURAL MATERIALS

A characteristic in the selection of civilian aircraft materials is to take the traditional high strength alloy 7075 and 2024 alloy, with relatively good toughness and antifatigue characteristics, to act as the main structural materials. Beginning from the 1960's, for the sake of adapting to the development of the aerospace industry, research and manufacture of aluminum alloys also adopted a very quick pace. This was mainly demonstrated in the several areas below:

1. Going Through New Heat Processing to Obtain Good Overall Performance

For example, after 2xxx series alloys go through artificial aging processing (obtaining T6 and T8 states), it clearly raises anticorrosion characteristics and strengths, facilitating utilization at relatively high temperatures. In order to improve 7xxx series high strength aluminum alloy antistress corrosion capabilities and break resistance, going through superaging, one after another, research produced antipeeling corrosion state T76, antistress corrosion state T73, as well as state T74 associated with relatively good overall performance. The appearance of these heat treatment states very greatly opened up utilization realms for deformation aluminum alloys, raising their safety during use. Because of this, despite the fact that these heat treatments will cause some drops in certain characteristics of materials (for example, strength indices), in order to obtain good overall performance, however, in a great many new aircraft, they are still being utilized to a large extent.

2. Large Reductions in Fe and Si Content Raises Aluminum Alloy Break Resistance

Beginning from the 1970's, one after the other, there appeared a batch of high purity, high toughness advanced alloys--for example, in the 2xxx series, 2124, 2224, and 2324 alloys; in the 7xxx series, 7175, and 7475 alloys, and so on. Experimentation verified that, among alloys, phase number, distribution, and form, as well as large, coarse secondary phase particles all had clear influences on alloy break resistance, and the latter in particular was the most severe. Particles in aluminum alloys generally were of 3 types:

(1) As far as large, coarse metallic compounds are concerned, size ranges are generally between 0.5 - 10 microns.

They are formed during ingot casting solidification or subsequent homogenization handling processes. These particles are normally undissolved compounds of such pollutants as Fe and Si, for example, $FeAl_3$, α-Al (Fe, Mn) Si, Al_7Cu_2Fe, and corresponding soluble compounds such as $CuAl_2$, Mg_2Si, Al_2CuMg, and so on. These types of particles do very great harm to toughness. Experimentation clearly demonstrates that planar cracking toughness associated with the same alloy containing less than 0.5% Fe+Si is twice as high as that containing over 1% Fe+Si.

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(2) With regard to relatively small submicron points of matter or diffusion substances, 0.05 - 0.5 microns, they are normally metal compounds containing transition metals Cr, Mn or Zr, for example, $Al_{20}CuMn_3$, $Al_{12}Mg_2Cr$, and $ZrAl_3$. This type of particle has relatively complicated influences on toughness, with both good and bad effects.

(3) In the case of fine precipitates, sizes reach 0.01 μm. They are formed during aging processes. They strengthen alloys. However, they have no great influence on toughness.

Because of this, reducing the amounts of Fe and Si pollutants in alloys is also nothing else than greatly reducing the possibility of the appearance of the first type of particles. 7475 alloy has become the aluminum alloy having the highest cracking toughness precisely because it contains the least Fe and Si pollutants (respectively < 0.12% and < 0.01%). However, at the same time, it should also be seen that drops in the amounts of pollutants contained necessarily cause material costs to rise. In conjunction with this, smelting and casting of alloys bring with them very many difficulties.

3. Adjusting Alloy Constituents and Adding Trace Amounts of Elements Raise Overall Performance

For example, such new alloys as 7075, 7150, 2048, and so on, are nothing else than this kind. 7050 and 7150 alloys, due to the increased addition of the amounts of Zn and Cu elements contained and increases in the proportions of Zn and Mg, make use of the element Zr to replace Cr in acting as crystal particle thinning agents. The result is that strength, toughness, and antistress corrosion capabilities associated with the alloys in question are all quite outstanding. Good hardening characteristics make them particularly appropriate for use in manufacturing key load bearing members with thick, large cross sections. In a comparison between 2048 alloy and 2024 alloy, the amount of Cu contained is somewhat smaller. However, it still makes the cracking toughness of the alloy in question, in the T851 state, increase nearly 100%. Of course, strength drops slightly.

4. Special Aluminum Alloys

Among these are included the Al-Li series alloys with the highest specific strengths--for example, such trademark alloys as 2091 and 8090, which are already in use in aircraft, as well as superplastic alloys, powder alloys, and so on, and so on.

Outside China, certain advanced civilian aircraft wing parts make great use of relatively advanced aluminum alloys--for example, aircraft wing upper wall plates and long purlins which opt for the use of 7150-T7651 thick plate. Lower wall plates are 2324-T39. Lower long purlins are 2224-T3511. Upper and lower edge pieces of forward and aft beams, respectively, are 7050-T76511 and 2224-T3511 alloy structural materials. Belly plates use 2324-T39 thick plates. Due to the use of these new materials and new technologies, it makes aircraft wing structure weights

lighter by 363kg. However, generally, structural materials used in civilian aircraft fuselages and wings are still old trademark materials such as 2024-T351 thick plate, -T3 thin plate, as well as 7075-T7651 thick plate, -T6 thin plate, -T76511 structural material, and so on. Their performance is slightly inferior. However, they are relatively stable and have relatively low cost.

III. STRUCTURAL MATERIAL ARRANGEMENT SUPERAGING PROCESSING

This is a new technology opted for in civilian aircraft. In it, wing long purlins are mostly processed from 7075-T76511 or T6511 structural materials. At the contact locations associated with two rods of structural material, it is necessary, on the basis of specialized standard superaging to form a T73511 state. The advantage of doing it this way is to make structural materials throughout maintain the high performance of T76 (or T6) states (T76 state strength is higher than T73 state by 5-6%). Moreover, at contact sections, it also has relatively high antistress corrosion cracking characteristics and fracture toughness, guaranteeing the strength characteristics of long purlins, and so on.

As far as structural material arrangement superaging technology and equipment are concerned, at the present time, we still are not too clear. It is estimated that there is a need for special aging ovens in order to guarantee contact locations being able to accurately superage to T73 state. Moreover, it also causes the transition zone between the two states to be limited within 889mm.

Besides this, in order to reduce aircraft structural weight, adequately tapping and exploiting the latent strengths of materials used, in certain civilian aircraft, large forged members and, in particular, die forged members are still very little used.

IV. UTILIZATION OF PRESTRETCHED WALL PLATES

In civilian aircraft, great use has been made of prestretched wall plates. For example, in the case of two pieces of upper wall plate, dimensions are respectively 11810mmx2570mmx19.05mm and 17020mmx2450mmx17.02mm. The material is 7075-T7651. Lower wall plates are also two pieces. The material is 2024-T351 alloy. Dimensions are, respectively, 11610mmx2530mmx7.8mm and 17240mmx2350mmx19.05mm. In terms of dimensions, despite the fact that exterior dimensions are all relatively large, in all cases, however, they are relatively thin. This is because aircraft wings still opt for the use of semi-hard shell type structure. Long purlins are all rivet joined (or screw connected) to wall plates. Relatively advanced modern aircraft, by contrast, opt a great deal for the use of integral reinforced wall panels mechanically processed from prestretched thick plates. This type of wall panel bears forces well and reduces rivet (or screw) connections as well as the troubles attendant with fuel tank seal problems.

In the tail surfaces, exterior section wall plates are relatively advanced. All are integral reinforced wall plate. They are processed from 41mm and 45mm thick prestretched 7075-T7351 alloy plate. Long purlins worked from upper wall plate are "I" forms. Lower wall plate long purlins are "⊥" forms.

V. MIRROR SURFACE POLISHED SKINS

Civilian aircraft fuselages opt a great deal for the use of 2024 and 7075 alloy mirror surface polished skins. This is a type of mirror surface skin of thickened aluminum envelope layer put through simultaneous mechanical polishing and the elimination of surface cracking. After going through polishing, skin is shiny and reflects images. In conjunction with this, it must go through strict technical checks. At the present time, in

the world, there are only a few countries capable of producing this kind of mirror surface plate.

The advantage of mirror surface polished skins, besides being able to make aircraft beautiful to look at, is mainly the elimination of material surface micro cracks. Thus, under repeated loads, the time limit for the appearance of cracking is delayed. The speed of crack expansion under the effects of repeated loading is reduced. Fuselage life is greatly increased. The amount of maintenance and repair work in utilization periods is lessened. At the same time, due to increases in surface anticorrosion characteristics, it reduces the aircraft surface lacquer film covering layer, and also achieves the advantage of weight reduction. Because of this, this type of skin has already achieved broad applications in modern passenger planes.

However, mirror surface skin, in comparison to structural skin, has costs that are considerably higher. Moreover, strict control during manufacturing processes and technological costs are also high. Because of this, with regard to fuselage surfaces of aircraft on which it is still necessary to spray paint or lacquer (for example, MD-82 aircraft purchased by the China East Is Red Aviation Company), whether or not to utilize this type of skin requires balanced treatment. Design personnel recognize that, if, domestically, it is possible to supply this type of material, and aircraft manufacturing plants are also capable of mastering production and manufacturing technology, from considerations of raising aircraft performance and reaching international advanced technology levels, it may be that selection for use of mirror surface polished skins is good.

In summary, selection of materials and technology for civilian aircraft has quite a few unique aspects to it. Moreover, these several special points are all subordinate to overall aircraft performance and structural design requirements.

In terms of materials selection, it guarantees aircraft safety, economic characteristics, comfort, beauty, as well as useful life.

APPLICATIONS OF COMPOSITES IN COMMERCIAL AIRCRAFT

Wang Shangen

I. FORWARD

At the present time, advanced composite materials are in the midst of a gradual expansion of their application in military aircraft. In a certain number of new models of fighter aircraft which are in the process of being test manufactured, applications of advanced composite materials even go to the point of accounting for 50-60% of the total structural weight. However, civilian aircraft act as transportation tools with the objective of flights carrying passengers regularly. Compared with military aircraft, reliability requirements with regard to aircraft structure and spare parts operations are even more strict. At the same time, there is particular stress on such things as economic characteristics, comfort, and long life. To this end, the number of applications of composite materials in civilian aircraft is still relatively small. Moreover, it has begun in order with load bearing members. Because proceeding in this way presents relatively small dangers, required basic data are few. However, weight reduction effects are very clear. There are advantages, with regard to various types of composite material components, from doing flight utilization evaluations in order to facilitate accumulating experience. Besides this, in structures, opting for the use of composite materials still requires performing large amounts of research work. However, in civilian aircraft, opting for the use of composite materials as well as what amounts of composite materials are used, at the present time, has already become one of the key indicators to decide whether or not civilian aircraft possess a technologically advanced nature. This article carries out a general description of the status of applications

of advanced composite materials in civilian aircraft as well as of experimental projects which need to be carried out and airworthiness requirements.

II. APPLICATION PARTS ASSOCIATED WITH COMPOSITE MATERIALS IN CIVILIAN AIRCRAFT

Based on introduction of relevant materials, the amounts of composite materials used in civilian aircraft are approximately 10%. This can be divided into two classes: one is structural use of composite materials; the second is materials in the cabin. The utilization components and locations are as shown in Fig.1 and Table 1. Adoption of the use of composite material components has already reached a maximum weight savings of 35%. The carbon fiber/epoxy system initially selected for use is the T300/5208 materials system. The utilization temperature is 120°C. Moreover, in hot, wet conditions, it is capable of maintaining outstanding dynamic performance. This type of resin system has achieved broad applications in the U.S. However, within cabins, phenol aldehyde resins are the materials selected for use. This is because the heat resistance is good, the flashpoint is high, combustion heat content is low, little smoke is produced, and noxious gases are also few. At the present time, companies producing civilian aircraft are in the process of exerting their efforts in the test manufacture of a composite materials system utilizing AS4 carbon fiber/3501-6 epoxy. This type of composite materials system possesses relatively strong antishock delamination capabilities.

III. TEST PROJECTS EVALUATING COMPOSITE MATERIALS PERFORMANCE

With regard to the application of composite materials to large model civilian aircraft, in the end, as concerns which performance tests ought to be carried out as critical in satisfying design requirements, outside China

large amounts of research have already been carried out. In conjunction with this, certain experience has been accumulated. Some has already come out as clear prescriptions. Presently, taking graphite/epoxy composite materials as an example, we set out the key test projects which ought to be carried out in utilizing composite materials in civilian aircraft.

TABLE 1 COMPOSITE MATERIALS COMPONENTS ADOPTED FOR USE IN CIVILIAN AIRCRAFT

A 部位及部件	B 材 料	C 应用效果
1. 机身尾部整流罩	13 开芙拉/环氧蒙皮，Nomex 蜂窝芯；刚性聚氨脂泡沫塑料，开芙拉/环氧面板，Nomex 蜂窝芯，铝边缘	25 减重 27%，改善弹性损伤
2. 厨柜	带聚乙烯薄膜的开芙拉/环氧面板，芳香性聚酰胺泡沫芯 14	26 减重 35%
3. 行李架	开芙拉/酚醛 15	每块减重 43.5kg 27
4. 发动机短舱舱门	开芙拉/碳纤维/环氧；蒙皮为开芙拉/环氧；碳/环氧层间混杂 16	28 减重 15%
5. 机翼-机身整流板	开芙拉/环氧 17	减重 30% 29
6. 方向舵组件	方向舵：碳纤维/环氧面板，Nomex 蜂窝芯；方向舵调整片：碳/环氧层压板 18	30 减重 27%
7. 副翼组件	副翼：碳纤维/环氧面板，全高度 Nomex 蜂窝芯；控制与调整片：碳/环氧层压板 19	31 减重 19%
8. 翼根后缘	开芙拉/环氧 20	
9. 阻流片	碳纤维/环氧面板，Nomex 蜂窝芯 21	减重 25% 32
10. 前舱服务员坐椅	碳纤维/环氧面板 22 铝与 Nomex 蜂窝芯	减重 29% 33
11. 非增压门	碳纤维/环氧 23	
12. 舱地板	碳纤维/酚醛面板，Nomex 蜂窝芯 24	34 减重 18kg

Key to table on following page.

Key: (A) Location and Component (B) Material (C) Application Results (1) Fuselage Tail Section Cowling (2) Galley Cabinets (3) Luggage Racks (4) Engine Nacelle Compartment Doors (5) Wing-Fuselage Cowling Plates (6) Rudder Assembly (7) Aileron Assembly (8) Tab Trailing Edges (9) Flow Resistance Plates (10) Forward Compartment Attendant Seats (11) Nonpressurized Doors (12) Compartment Floors (13) Kevlar/epoxy skin, Nomex honeycomb core; rigid polyurethane foam plastic, Kevlar/epoxy surface plates, Nomex honeycomb core, aluminum edges (14) Kevlar with a thin polyethylene film/epoxy surface plates, scented polyamide foam core (15) Kevlar/phenol aldehyde (16) Kevlar/carbon fiber/epoxy; skin is Kevlar/epoxy; carbon epoxy mix between layers (17) Kevlar/epoxy (18) rudder: carbon fiber/epoxy surface plates, Nomex honeycomb core; rudder adjustment plates: carbon/epoxy laminated plates (19) ailerons: carbon fiber/epoxy surface plates, full height Nomex honeycomb core; control and adjustment plates: carbon/epoxy laminated plates (20) Kevlar/epoxy (21) carbon fiber/epoxy surface plates, Nomex honeycomb core (22) carbon fiber/epoxy surface plates aluminum and Nomex honeycomb core (23) carbon fiber/epoxy (24) carbon fiber/phenol aldehyde surface plates, Nomex honeycomb core (25) weight reduction 27%, improved elasticity losses (26) weight reduction 35% (27) weight reduction per piece 43.5 kg (28) weight reduction 15% (29) weight reduction 30% (30) weight reduction 27% (31) weight reduction 19% (32) weight reduction 25% (33) weight reduction 29% (34) weight reduction 18kg

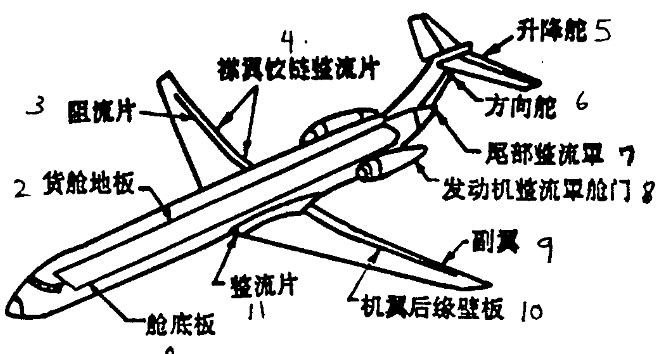

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Fig.1 Civilian Aircraft Composite Material Application Locations

Key:(1) Cabin Floor (2) Cargo Compartment Floor (3) Flow Resistance Plate (4) Flap Hinge Flow Adjustment Plate (5) Elevator (6) Rudder (7) Tail Cowling (8) Engine Cowling Compartment Door (9) Aileron (10) Wing Trailing Edge Wall Plate (11) Flow Adjustment Plate (12) Component Weight Savings: 21%

1. Physical Performance of Presoaked Materials

Measure amount of volatile substances contained;
Measure amount of resin contained;
Presoaked material viscosity;
Presoaked material snapping characteristics;
Geling time;
Fiber unit surface area weight.

2. Composite Material Laminated Plate Mechanical Performance

Unidirectional composite material vertical tensile strength and modulus as well as vertical compression strength and modulus;

Unidirectional composite material horizontal tensile strength and modulus;

Unidirectional composite material vertical bending resistance and modulus;

Unidirectional composite material vertical short beam shear strength.

3. Environmental Resistance Performance

(1) After 121°C/30d heat aging, test measurements done at 121°C:

Unidirectional composite material bending resistance and modulus;

Unidirectional composite material vertical short beam shear strength;

Unidirectional composite material vertical tensile strength and modulus;

Unidirectional composite material vertical compression strength and modulus.

(2) After carrying out 30d treatment at 60°C/95% relative humidity, determinations at normal atmospheric temperature and 121°C:

Composite material vertical bending resistance and modulus;

Composite material vertical short beam shear strength.

(3) After media resistance (various types of media are: phosphate ester, JP4 fuel, salt spray, and so on), determine bending resistance and short beam shear strength.

4. Other Performance (Primarily Refers to Internal Decoration Materials)

Includes: shock resistance tests, interlamination pulling, combustion tests, smoke concentration tests, abrasion resistance characteristics, Bell peeling, bolt connection strength, and so on.

Besides this, materials inside the cabins of civilian aircraft are required to possess safety and comfort. The key requirements are:

(1) they ought to be self extinguishing materials, possess low flammability, produce low smoke and toxic gases when they burn, and have low heat release speed, in order to raise passenger cabin antifire capabilities after having sustained collapse and destruction:

(2) possess definite strength and rigidity, good dimensional stability, have small moisture absorption, counter vibration and resist shock:

(3) possess good sound and heat insulation characteristics, be good looking and easy to clean, and be an environment that makes travelers comfortable.

IV. AIRWORTHINESS REQUIREMENTS ASSOCIATED WITH COMPOSITE MATERIALS AND TECHNOLOGY

At the present time, the composite material components which are already used in large civilian aircraft have all gone through U.S. Federal Aviation Agency (FAA) evaluation. This means that these composite material structural members all satisfy U.S. Federal Aviation Agency transportation department AC-NO.20-10TA consultative bulletin requirements. On the basis of bulletin article 5, the consultative bulletin in question mainly has requirements concerning composite material design and manufacture associated with the several areas below:

1. Set Up Environmental Design Standards

Composite material applicability and durability requirements should conform to FAR25, article 603.

First of all, there should be precise specification of what harsh environmental conditions are. After that, under these environmental conditions, carry out tests on material systems. The material systems which are tested must pass materials standards recognized as acceptable and approved by airworthiness agencies, not allowing the blind selection of materials.

In critical environmental uses, materials should possess design values associated with high credibility or allowable values. Going through analysis, it is recognized that the highest utilization temperature is 82°C. The lowest temperature is -59°C. Moisture absorption content is 1%.

2. Set Up Materials Design Allowable Values

On the basis of the requirements of consultative bulletins, materials design allowable values should "go through analytical methods experimentally verified by laminar plate tests or through unidirectional laminar plate tests in order to be determined."

What must be explained is that materials used in experiments must go through airworthiness management agency approval and that the number of tests and batch iterations should conform to MIL-HDBK-17 or the stipulations of military manual 5.C. In conjunction with this, using scientific statistical methods, analytical treatment should be carried out on data.

As far as the three types of allowable values normally given for strength performance--"A", "B", and "C"--are concerned, the credibility associated with "A" standard values is 95%, and probability is 99%; the credibility associated with "B" standard values is 95%, and probability is 90%; "S" values are the minimum values given in the standard. When calculating A and B values, so long as there are no errors in technology or experimental methods, all experimental data, including data which does not fit standards, should all be figured in statistically.

3. Use Levels Associated with Limitation Design Strains in Order to Adapt Shock Loss Requirements

Breaking strains measured for basic materials performance are:

A standard: $\varepsilon_{tensile} = 0.0082$,
$\varepsilon_{compression} = 0.0067$,
$\varepsilon_{shear} = 0.0133$;

B standard: $\varepsilon_{tensile} = 0.0090$,
$\varepsilon_{compression} = 0.0072$,
$\varepsilon_{shear} = 0.0144$.

Normal aircraft industry allowable strain values are as follows:

$\varepsilon_{tensile} = 0.0035$,
$\varepsilon_{compression} = 0.0027$,
$\varepsilon_{shear} = 0.0053$.

From this it can be seen that, during design, allowable strain values which are selected for use should be approximately only 30-40% of breaking strain values. After making this type of stipulation, other various types of influencing factors need not be considered again. In this way, it is nothing else than taking a complicated problem in engineering applications and simplifying it.

FORGING TECHNOLOGY OF LARGE SIZE FORGINGS FOR COMMERCIAL AIRCRAFT

Wang Lean

This article opts for the use of actual examples of forging technology having positive and negative effects on aviation products to explain that forging technology is a key mainstay technology of the aviation industry. It analyzes the special characteristics of civilian aircraft forged member production as well as the key technological requirements. Representative forging technology associated with large forged aircraft members outside China is introduced. In order to adapt to civilian aircraft test production requirements, it is suggested that a beginning should be made from the two areas of strengthening quality control management and forging technology reform to speed up the development of Chinese forging technology.

I. EFFECTS OF FORGING TECHNOLOGY IN THE AVIATION INDUSTRY

Types of forged aircraft members are diverse. Their forms get more complicated every day. Their dimensions grow larger and larger. They are distributed throughout various locations in aircraft fuselage, wings, landing gear, and so on (Fig.1). Moreover, many are key load bearing members that determine levels of maximum aircraft performance, life, and reliability--for example, landing gear, beams, connectors, as well as bulkheads, and so on. Because of this, quality requirements get higher and higher. Advanced forging technology is capable of making aircraft weights lighter, increasing range, and bringing huge economic benefits. On the basis of reports, reducing aircraft fuselage weight 5kg makes it possible to reduce aircraft take off weight by 50kg. Because of this, designers reduce aircraft weight by every possible means. Sometimes, in the end, great pains are taken over several tens of grams of weight. With this

the case, opting for the use of large integral forged members, however, is capable of reducing aircraft weight by several tens, several hundreds, and even into the thousands of kilograms--for example, in the case of 747 aircraft landing gear beams, after changing to the use of 45,000 ton hydraulic die forged integral titanium alloy beams, each aircraft, opting for the use of four similar beams, could reduce weight 113.5kg. An-22 transport plane fuselages, opting for the use of 20 large bulkhead forged members, cut 800 types of spare parts and lighten the aircraft weight 1t, reducing mechanical processing time 15-20%. Conversely, if forged technology is backward, it can even go so far as to have disastrous influences on the aviation industry--for example, according to U.S. 1962 aircraft accident statistics, accidents associated with manufacturing problems due to technology and materials quality accounted for 65%. Among these, forging quality accidents were 40%, accounting for more than half. Because of this, western scholars take forging technology--in particular, large forged member manufacturing technology--to be a key index in evaluating the level of a nation's aviation industry. Forging technology has already become a key technology mainstay of aviation--in particular, the civil aviation industry, and, speaking in terms of certain types of significance, the capability to produce large forged members represents the actual strength of the aviation industry.

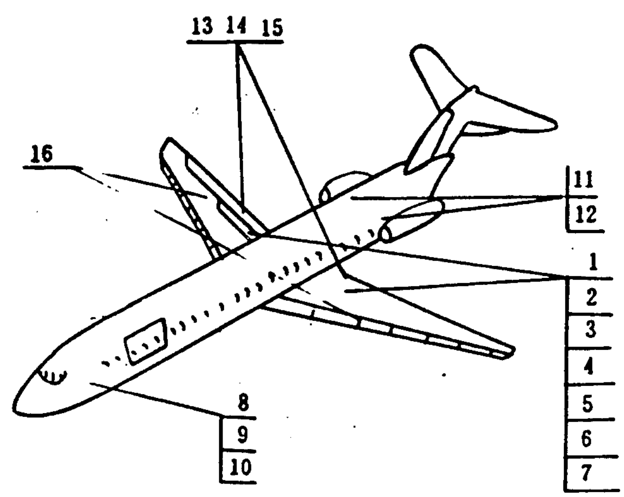

Fig.1 Distribution Chart of Key Large Forged Members in Civilian Aircraft

Key on following page.

Key: (1) Main Landing Gear Outer Sleeves (2) Main Landing Gear Support Connectors (3) Main Landing Gear Torque Arms (4) Main Landing Gear Upper Support Connecting Rods (5) Main Landing Gear Lower Support Connecting Rods (6) Main Landing Gear Piston Rods (7) Main Landing Gear Brake Connecting Rod Beams (8) Forward Landing Gear Outer Sleeves (9) Forward Landing Gear Piston Rods (10) Forward Landing Gear Torque Arms (11) Forward Engine Suspension Beams (12) Engine Forward Installation Connectors (13) Flap Hinge Connectors (14) Interior Flap Conveyors (15) Interior Flap Conveyor Support Connectors (16) Leading Edge Crack Wing Conveyor

II. SPECIAL NATURE OF PRODUCING CIVILIAN AIRCRAFT FORGED MEMBERS

Due to the fact that aircraft for civilian use (called simply civil aircraft) have even more strict requirements than military aircraft in such areas as reliability, economics, comfort, and life, internationally, universal quotations are made from the U.S. Federal Aviation Agency (FAA) aviation regulations (FAR) to act as national laws and decrees in order to strengthen the work of quality management and control with respect to /7
civilian aircraft. In accordance with the stipulations of U.S. Federal Aviation Agency regulations, companies manufacturing and providing externally purchased forged members are recognized to be aircraft manufacturing companies with approved extensions of production permits, and the production, quality, and standards of companies supplying forged members as well as full production processes must all receive evaluation, approval, control, and supervision from national airworthiness bureaus or authorized aircraft manufacturing companies. Because of this, factories preparing to produce civilian aircraft forged members, first of all, must submit applications, go through evaluations of standards, issuance of production permits, and, after that, only then do they get qualifications to produce civilian aircraft forged members.

Civilian aircraft forged members are divided into two classes and two grades on the basis of their importance, load

bearing status, and relative safety margins. Class 1 is forging technology which requires passing evaluations and approval for key forged members (that is, plants obtaining production permits must produce Class 1 forged members; they also require the carrying out of certification evaluations and approval of the forging technology). Class 2 is forging technology which does not require certification evaluations and approval of forged members. Grade A is forged members which require checks of cracking toughness. Grade A forged members of certain steels, by contrast, are stipulated to require opting for the use of vacuum self-consuming remelted steel materials. Grade B is forged members that do not require checks of cracking toughness. Grade B forged components of some steels, by contrast, are specified as being able to opt for the use of steel materials produced by other suitable smelting technology. If engineering diagrams do not have stipulations, then, Class 2 Grade B forged members are supplied.

The special points of this type of quality management method are opting for the use of top quality raw materials, good production environment and manufacturing technology. In conjunction with this, it relys on supervision and control apparatus sampling checks during the work process in order to carry out supervision and control of forged member quality. Actualization clearly demonstrates that this type of management method for whole industrial processes--uniting together prevention and testing--compared to past passive type management methods in which forged members for military aircraft, after each work process, had carried out extensive tests on forged members, finally eliminating items that did not pass, is more able to guarantee forged member quality.

III. KEY TECHNOLOGICAL REQUIREMENTS REGARDING FORGED MEMBERS

1. Technical Requirements

(1) Certification evaluation approval: Class 1 forged member forging technology requires certification evaluation approval. As far as technology which has already been approved is concerned, without going through written approval of the aircraft manufacturing company, it is not possible to change forging processes and technological methods. During production of forged member first production batches and subsequent production, at times when changes in forged member plans or changes in forging technology influence streamlining or mechanical performance as well as when there are changes in the companies and plants supplying forged members, in all cases, it is necessary to carry out forging technology certification evaluation approval. The key contents checked in certification evaluation approval include:

-1- forging technology plans: includes the whole industrial process plan from cutting the forging stock to final checks of the forged members;

-2- forged member plans and sampling locations;

-3- certification test contents, includes: streamlining, mechanical performance, and degree of crystallization.

(2) Forging stock: check streamlining and low power and high power structures.

(3) Surface state: forging member surface pits should be removed by the use of polishing, file or cutting work methods; there are some die forged members that also should undergo magnetic powder or florescence tests.

(4) Heat treatment: heat treatment programs, temperature uniformity, instruments, furnace loading, temperature maintenance, as well as cooling, and other similar items, all have strict specifications.

(5) Carburization and decarbonization: die cast members should not have carburization layers, and decarbonization layers should not exceed a maximum depth of 0.76mm. It is not permitted to use carbon restoration treatment in order to correct excessive decarbonization.

(6) Supersonic checks: forged member supersonic checks should be carried out in accordance with A grade, 1 type methods in MIL-STD-2154. It is necessary that supersonic checks of A grade forged members should be carried out on each forged member. In conjunction with this, it is not permitted to use forged member prefabricated stock or forged stock to replace them. However, in the case of B grade forged members, by contrast, it is permissible to use forged member prefabricated stock or forged stock to replace forged members in carrying out supersonic checks.

(7) Mechanical performance: there are clear specifications for all vertical and transverse properties of each type of material.

(8) Breaking toughness: only applicable to Grade A forged members.

(9) Degree of Crystallization: The degree of crystallization associated with low alloy steel should mainly be ATSM No.6. It is permissible for individual crystals to reach No.4 sizes.

(10) Free forged multi-item stock: should not be short transverse directional.

(11) Forged members carrying extension sections: extension sections added to forged members in order to do performance tests should be removed after forging.

(12) Ability to track: forged members should be traceable to the smelting furnace no.

(13) Product marks: each forged member should be marked with part no., smelting no., batch no., and supplying firm symbol.

(14) Manufacturing quality: forged members should be of uniform and integrated quality and state, without foreign matter harmful to subsequent part manufacture and performance as well as flaws such as holes, burrs, folds, cracking, cracked edges, folding fractures, crackle, severe bending, or inclusions, and so on.

2. Forged Member Diagrams

The contents of the forged member diagrams associated with die forged members universal in civilian aircraft outside China as well as of the stipulations in explanatory notes are:

(1) die dividing lines, die forging angles, and streamlining directions;

(2) belly plates and ribs, including belly plate thickness and rib width to height ratios, concave cavities, concave grooves, as well as thin belly plate punching requirements;

(3) interior and exterior circular angle radii;

(4) length and width tolerances, interior and exterior circular angle radii tolerances, die closure, die error, steps, amount of flight edge excess, degree of flatness and levelness as well as mechanical working margins;

(5) degree of surface roughness, manufacturing convex platforms, and marks, etc.

3. Manufacturing Process Datum Plane--Datum Points

Forged members opt for the use of ANSI Y14.5M--1982 datum plane--datum point marked dimension methods. The methods in question opt for the use of 6 manufacturing process datum points on 3 mutually perpendicular datum planes in order to carry out placement of forged members as well as marking dimensions and checking, as is shown in Fig.2. There are 3 manufacturing datum points 1, 2, and 3, not in a straight line, on datum plane A

parallel to the largest surface of forged members. On datum plane B (the second largest surface of forged members), perpendicular to datum plane A, set datum points 4 and 5. Then, datum point 6 is set on datum plane C, perpendicular to datum planes A and B. This type of marked dimension method guarantees that, throughout the entire manufacturing and inspection process, the same type of index points are selected for use, giving a consistent placement method to the manufacture, checking, and final mechanical working of forged members and parts. This simplifies requirements or checks between the two areas of forging and mechanical working.

IV. TYPICAL FORGING TECHNOLOGY ASSOCIATED WITH LARGE FORGED AIRCRAFT MEMBERS

The forms of large forged aircraft members are complicated. The dimensions are large. Quality requirements are high. Current forging equipment has very large limitations. Because of this, quite a few forged members usually require the coordination of multiple types of equipment and multiple sets of dies, and, only then is it possible to produce them. From the actual case of the Wyman-Gorden Company's aircraft forged member manufacturing, it is possible to see this trend.

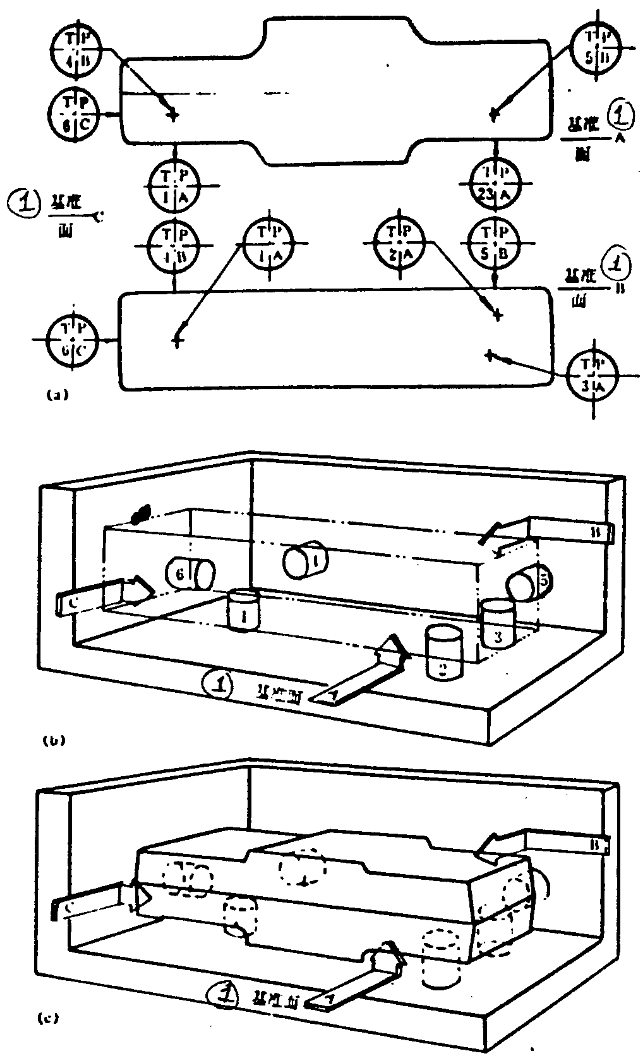

Fig.2 Manufacturing Datum Points Associated with Forged Member Diagrams

Key: (a), Corresponding Test Die (b), and Die Carrying the Forged Member (c)

1. Boeing 747 Aircraft Landing Gear Beam Forged Members

The forged members in question are made by die forging from Ti-6Al-4V titanium alloy. Exterior dimensions are 865mmx6600mm. Projection surface area is 2.58m^2. Forged member weight is 1800kg. Part weight is 798kg. The forging process is as follows:

(1) Square billet side length is 483mm. A circular saw or friction is used to saw off material.

(2) Unfinished product stock is heated in platform car type furnaces.

(3) Use 1800t free forging hydraulic press to form stock;

(4) Acid pickling and cleaning of surface flaws;

(5) Carry out 3 iterations of die forging on a 45000t hydraulic press. After each iteration of forging, carry out edge cutting (using edge cutting presses or flame cutting methods), clean up and inspect;

(6) In a platform car type furnace, anneal to remove residual stresses, clean up and inspect;

(7) Nondestructive inspection (surface fluorescence inspection and interior quality ultrasound or X-ray inspection) as well as inspections of degrees of crystallization at specified locations;

(8) Chemically mill off the α shell layer. In conjunction with this, carry out dimensional checks.

(9) On a numerically controlled horizontal milling machine, rough work manufacturing standards;

(10) Cut off test samples from forged members and carry out complete performance checks.

As far as the work processes for forging the beams in question are concerned, there were 57 runs all together, with figures of 1,000,000 U.S dollars used in manufacturing equipment costs.

2. C-5A Aircraft Main Landing Gear Outer Sleeve Forged Members

As far as the members in question are concerned, ordinary die forged members are formed from 300M super high strength steel die forging. Forged member outer dimensions are 1470mmx1620mm (interior aperture diameter 364mm). Forged component weight is 1088kg. Forging stock weight is 1650kg. The forging process is as follows:

(1) Take hexagonal cross section stock material and cut it to determined lengths;

(2) Heating unfinished product blanks, in a 16200t die forging hydraulic press, do local rough forging, and, in a 1500t free forging hydraulic press, press flat head sections, clean them up and sand them;

(3) Heat again, and, in a 700t free forging hydraulic press, stretch out the rod portions, bury, cool, and clean up, and inspect;

(4) Heat for the third time, and, in a 45000t die forging hydraulic press, preforge; flame cut edges;

(5) Heat for the fourth time, and, in a 45000t die forging hydraulic press, rough forge; in a 3000t hydraulic press, cut edges, bury, cool, clean up, and inspect;

(6) Heat for the fifth time, and, in a 45000t die forging hydraulic press, final forge; in a 3000t hydraulic press, cut edges, bury, cool, clean up, and inspect;

(7) Heat for the sixth time, and, in a 31500t die forging hydraulic press, reverse extrude interior apertures, bury, cool, clean up, and inspect;

(8) Rough work;

(9) Heat treat, clean up, chemically test, and inspect.

With regard to the forged members in question, forging dies used had a total weight of 120.6t.

V. SUGGESTIONS FOR DEVELOPING DOMESTIC PRODUCTION OF AIRCRAFT FORGED MEMBERS

To summarize what was described above, due to the fact that large forged members are all key load bearing members composing aircraft frames, their manufacturing technology level also holds the balancing influence for aircraft reliability, performance, as well as technological and economic indicators. Because of this, the aviation industry takes manufacturing technology for large forged members to be a mainstay technology. Manufacturing technology for large forged members in civilian aircraft represents the highest technological level for large die forged members in this era. Outside China, in this key technological realm, quite high levels have already been reached. However, China, in this area, is still very backward. In order to adapt to the requirements of test manufacturing civilian aircraft, it is suggested that, beginning from the two areas of management and forging technology, China's large forged member manufacturing technology be improved.

1. In accordance with international conventions, in civilian aircraft forged member production plants, set up quality assurance systems conforming to airworthiness management regulations in order to absolutely guarantee forged member production quality, obtain the approval of China civil aviation airworthiness authorities as quickly as possible, and enter the international civil aviation market.

2. Forging technology reform includes forging equipment and forging manufacturing process reforms:

(1) Forging equipment technology reform

In the case of auxiliary equipment associated with China's large die forging equipment--for example, stock manufacturing equipment, heating furnaces, and operating devices, etc--all, to different degrees, do not conform to modern forging and

airworthiness management requirements. Technology reform should be carried out in order to adequately show forth the capabilities of large forging equipment currently on hand.

(2) Technology reform associated with forging industrial processes

Forging of large forged members in China is, basically, still 1950's die forging technology. Work processes and dies are mainly designed relying on experience. Due to the fact that test manufacturing costs associated with large forged members are high, they do not permit the use of actual items in carrying out tests. Even less is failure permissible. Because of this, there is nothing else to do but opt for the use of conservative industrial processes. In addition, as far as limitations on the energies of large forging equipment are concerned, it is difficult to produce even larger forged members. Moreover, forged member remnants are large, dressing materials are many, dimension precision is bad, and quality is low. It is not possible to satisfy modern aircraft requirements for large forged members. On the basis of the current situation in which large forging equipment capabilities are small and product types and numbers are few, there is an urgent need to develop research on sectioned die technology, die forging technology putting together partial dies, as well as isothermal die forging technology, and other similar technological methods. In conjunction with this, strengthen such basic research work as simulation technology associated with lubrication technology and forging processes in order to bring out and develop capabilities of forging equipment currently on hand, producing forged members with large dimensions in large numbers and good quality.

FOREIGN PAGES 9-15 MISSING FROM ORIGINAL FOREIGN TEXT.

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THE PRODUCTION AND THE FUTURE DEVELOPMENT OF LARGE SIZE DIE FORGING FOR COMMERCIAL AIRCRAFT

Xu Haoyi Le An

ABSTRACT

This article goes through studies of Boeing aircraft titanium forged member die forging technology and production practice, taking actual cases of forging to explain the characteristics of die forging technology associated with large titanium forged members. It introduces technology reform in the near future at the Hongyuan Forging & Casting Plant and the outlook for future development.

I. FORWARD

Until the middle of the 1980's, Chinese production of high quality large die forged members for civilian use aircraft (simply called civil aircraft) was still a blank. In order to adapt to the requirements of test manufacturing civilian aircraft, a form was worked out which mutually combines technology and trade as well as plans for the development of the production of larged forged members for Chinese civilian aircraft in accordance with advanced international standards. According to these plans, the Hongyuan Forging & Casting Plant, in 1983, signed an agreement with the Boeing Aircraft Co. to test manufacture OF Boeing 747 aircraft titanium alloy forged members. With the help of the Beijing Aviation Materials Research Institute, in 1984, 3 types were test manufactured on 250kJ paired striking hammers--a total of 12 forged members. The Boeing Aircraft Co. went through checks on Chinese personnel, equipment, production environment, and quality assurance systems,

as well as tests on the initial batch of 12 forged members. In November, 1985, qualifications for the Hongyuan Forging & Casting Plant to manufacture Boeing Aircraft Co. titanium forged members were granted. In conjunction with this, overseas contractor certificates were issued. 257 parts produced subsequently (4 member no.'s) of Ti-6Al-4V titanium alloy forging were all tested and passed in April, 1986. After going into production with 400kJ and 630kJ paired striking hammers, the Boeing Aircraft Co. also added 8 types of even larger forged members to the order. Up to 1991, a total of 12 types had been delivered of over 4200 titanium alloy forged members which met the standard. In 1992, an agreement was also signed with the Boeing Aircraft Co. to produce 2400 titanium forged members.

Through the efforts of the last 10 years, the Hongyuan Forging & Casting Plant has already formed the capability to produce titanium forged members at an international level. Titanium forged members produced have already entered the international market in mass quantities and have reaped a bumper harvest of technological progress and economic benefit.

II. ACTUAL CASES OF CIVILIAN AIRCRAFT TITANIUM FORGED MEMBER DIE FORGING WORK PROCESSES

What Fig.1 shows is the exterior plan (schematic) of a Boeing 747 aircraft lower cabin connector forged member. The key forging work processes are as follows:

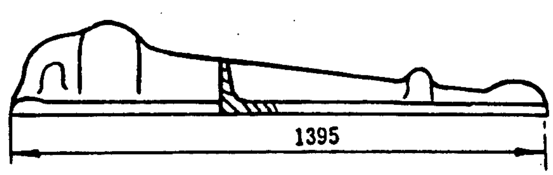

Fig.1 Exterior Schematic of Lower Cabin Connector Forged Member

1. Preparing Materials

Ti-6Al-4V titanium alloy material with a diameter of 127mm is sawed into unit pieces using a G601 circular saw. The length is 770mm. Weight is 43.1kg.

2. Working Stock

Using an RJX-75-9 mesothermal box type electric furnace to add heat up to 930 ± 10°C, on a 3t free forging hammer, 2 pyroforgings are used to reach the form and dimensions in Fig.2.

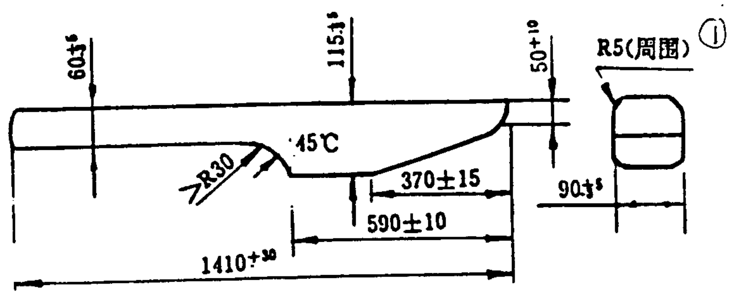

Fig.2 Lower Cabin Connector Premanufacture Stock Diagram (1) Peripheral Contour

3. Cleaning Up

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Blow off the grit and polish surface flaws.

4. Spraying On Protective Lubricant

After taking semifinished product blanks and preheating them to 100°C, spray on FR-5 glass protective lubricant.

5. Die Forging

Use an RJX high temperature box type electric furnace to heat up to 930 ± 10°C. On 250kJ paired striking hammers (later changed to the use of 400kJ), do preforging. Following this, reclean, spray protective lubricants and heat. In conjunction with this, take upper and lower moulds and install them on each other, carrying out final forging.

6. Cutting Edges

After preforging, gas cut blank edges. After final forging, use a 10000kN oil hydraulic press to cut blank edges.

7. Cleaning Up

Blow away the grit and polish surface flaws.

8. Corrections

Heat up to 900 ± 10°C. On 250kJ paired striking hammers, use final forging die corrections.

9. Heat Treatment

In an 18SH-33 moving furnace base electric furnace, heat to 780°C ± 10°C. Maintain the temperature for 2h. Air cool.

10. Chemical Milling

In a specialized chemical milling trough, according to standards, take off the brittle α layer.

11. Inspections and Tests

Carry out shape inspections of 100% of forged components, dimensional checks, and ultrasonic wave flaw detection. In conjunction with this, spot check metal phase structure, mechanical properties, as well as amounts of H_2 included.

III. LARGE CIVILIAN AIRCRAFT FORGED MEMBERS AND THEIR FORGING CHARACTERISTICS

1. Large Civilian Aircraft Forged Member Characteristics

Civilian aircraft forged member production definitely has special characteristics. Among them, the most outstanding is that aircraft for civilian use, in such areas as safety and life, have even more strict requirements than do aircraft for military use. Because of this, quality requirements for key load bearing members are also even higher. Normally, large forged members are all externally procured items by the main plane factory. In order to guarantee forged member quality, on the basis of international convention, it is necessary to carry out production qualifications and authorizations with the plant undertaking the manufacture of forged members. In conjunction with this, approvals of industrial techniques are carried out with regard to forging technology associated with key forged members.

Due to the fact that projection surface areas of large forged members are large and forms are complicated, it is necessary to coordinate with each other multiple types of high power forging equipment and many firing form changes. Only then is it possible to produce them. However, high quality requirements, by contrast, hope for the use of as few as possible complete firing iteration form changes in order to forge. This adds even more to the difficulty of forging.

2. Forging Characteristics of Titanium Forged Members

(1) Chemical properties of titanium are reactive. In the process of plastic deformations, the fresh surfaces that are formed easily adhere to moulds. This leads to forged members and moulds being discarded. Titanium, in forging temperature ranges as well as acid pickling processes, easily absorbs hydrogen. After hydrogen content exceeds a certain value, it makes parts sensitive to corresponding force concentrations. Shock toughness and notch strength clearly fall. At forging temperatures, titanium forged member surfaces and the α phase stable elements oxygen and nitrogen in air function to form solid solutions in gaps as well as metallic compounds (such as TiO_2, Ti_2O_3, TiO, as well as nitride, and so on). This type of surface layer, which is entirely or mostly composed of α phases, is very hard. During subsequent working, cutting tool life falls off very, very greatly. With regard to surfaces not worked, by contrast, there is a clear drop in part fatigue life.

(2) Titanium alloy plasticity is bad. Deformation resistance forces are great. Fluidity and pouring characteristics are bad. It not only requires high powered forging equipment, but is also difficult to fill up dies and cavities with.

(3) Titanium alloy deformation temperature ranges are narrow. Temperature sensitivity is great, and thermal conductivity is bad. During deformation, it is easy to cause large interior-exterior temperature differentials and produce nonuniform structures.

IV. TECHNOLOGICAL MEASURES TO PRODUCE HIGH QUALITY LARGE FORGED TITANIUM MEMBERS

All the characteristics described above--to one degree or another--add to the complexity of forging technology. This is particularly difficult with regard to paired striking hammer forging using top and bottom hammer heads moving together and striking multiple times to make forms. The main technology measures adopted to overcome these problems are:

1. Carry Out Protective Lubrication of Semifinished Product Blanks

In order to guard against titanium alloy forged members adhering to moulds during forging processes, absorbing hydrogen, and surfaces forming brittle layers of oxygen and nitrogen compounds, to improve pouring characteristics as well as dropping deformation resistance forces, besides doing conventional lubrication of forging dies, it is also necessary, before adding heat, to carry out protection of semifinished product blanks as well as carrying out lubrication of semifinished product blanks during forging. Successful experience inside and outside of China is to take glass lubricant and spread it on semifinished product blanks. In this way, it is possible to obtain double effects of protection and lubrication. The concrete method is: as concerns glass lubricants appropriate to apply to semifinished product blanks before heating, during heating processes, they follow the semifinished product blanks and go up in temperature. The glass material softens forming a continuous colloid film following along the semifinished product blanks, preventing the invasion of H_2, O_2, and N_2 in furnace gases. In conjunction with this, during forging processes, following the metal's continuous movements, it prevents titanium metal and mould cavity contact. After forging, during cooling processes, it still maintains a continuous film covering on entire forged

member surfaces in order to prevent the invasion of harmful gases in the atmosphere. Some glass lubricants are also capable--at low temperatures-- of self striping, in order to reduce the amount of work in cleaning up. Through experience, with regard to Ti-6Al-4V titanium alloy semifinished product blanks forged with heating of 930°C, spraying a 0.1-0.3mm thick FR-5 glass lubricant layer, it is possible to obtain the dual effects of good protection and lubrication.

2. Control Deformation Temperatures to Prevent Forged Member Core Coarse Crystals

During test manufacture of Ti-6Al-4V titanium alloy lower cabin connector forged members, it was discovered that cross section cores showed the appearance of low multiple coarse crystals (the original material had no coarse crystals). Analysis recognized that this was due to high forging hammer strike speeds and large amounts of deformation. Thermal effects caused forged member core temperatures to rise. In conjunction with this, they reached or surpassed the α-β phase change point and that caused it. After taking the original heating of 950°C and 70% deformation and changing them to be 930°C heating and 50% deformation, this type of coarse crystal flaw was then avoided.

3. Measures to Improve High Rib Top End Pouring Characteristics

Lower cabin connector heads are long rod forged members with "L" shaped cross sections. The length is 1395mm. The projection area is $0.2m^2$ (Fig.1). In order to simplify mould manufacture and avoid erroneous forged member displacements, take the whole mould cavity and put it into the lower die. The upper die becomes a flat plate die. With regard to the forged members in question, 250kJ paired striking hammer energies are on the low

side; adding in that rib heights are large and, after contacting the die cavity, heat dissipation is rapid, as well as titanium alloy pouring characteristics being bad, and other similar special points, rib top ends are usually not filled full. As far as resolving this difficult problem is concerned, besides general measures such as adopting the correct utilization of FR-5 semifinished product blank lubricant, adding gas storage compartments to the two ends of rib die cavities, raising mould preheating temperatures, guaranteeing forging hammer rated operating pressures, as well as raising operation speeds, and so on, also, on flat plate dies, work convex platforms for industrial techniques at two locations. On the first firing, do a preforging work sequence, lightly forging convex platforms for industrial techniques at two locations. After that, fit upper and lower moulds together, taking the flat plate die to act as the lower mould in order to fix industrial technique convex platform locations. Carry out final forging with full force. This greatly reduces the contact time between forged member rib sections and mould cavities, reducing temperature drop, improving filling conditions, and satisfactorily resolving the problem of filling rib top ends full.

4. Eliminating α Brittle Layers and Controlling Hydrogen Content

As was described above, it goes without saying that brittle α layers, with regard to working surfaces, are still nonworking surfaces and harmful in all cases. There is normally a requirement, before delivering forged members, to use chemical milling methods to eliminate them. However, if chemical milling industrial techniques are not controlled properly, then, forged members absorb excessive amounts of hydrogen. This leads to drops in forged member performance. Through experimentation--with regard to forging conditions in the plant in question--after forging and heat treatment, Ti-6Al-4V forged titanium alloy

members possess 0.2-0.4mm thick α layers. Chemical milling in accordance with the parameters described below is not only capable of completely eliminating α layers but will also cause amounts of hydrogen contained not to exceed requirements (test manufactured batches were 75ppm; batch process was ≤150ppm):

Channel liquid constituents (weight ratios)%: HF: 4-10, HNO_3: 20-30, H_2O: 76-60; in conjunction with this, add in appropriate amounts of titanium scrap;

Channel liquid temperature, °C: 40-80;

Chemical milling time, min: 5-30;

30 batches were chemically milled in accordance with these standards. Increases in the amounts of hydrogen contained in forged members lay in the range of 5-20ppm.

V. RECENT TECHNOLOGY REFORMS

Due to the fact that Boeing aircraft forged titanium alloy members batch processed by the Hongyuan Forging & Casting Plant have already reached foreign levels for the same types of products, and prices are slightly below the international market, the result is that, recently, there have been several famous aircraft manufacturing companies come to the plant to hold talks on producing large die forged members. In order to adapt to Chinese requirements for the test production of civilian aircraft and to increase and strengthen export capabilities associated with large forged members, technology levels and production capabilities should be raised another step on the currently existing foundation in order to make them capable of producing general steel and high temperature alloy die forged members with projection surfaces of $0.8m^2$ and weights of 1 ton as well as small aluminum alloy and titanium alloy precision forged members, facilitating the adequate exploitation of the capabilities of

630kJ paired strike hammers and 31500kN oil presses. To this end, it is necessary to carry out technological reforms in the two areas of currently existing industrial die forging technology methods and equipment.

1. Equipment

(1) At the present time, the largest stock working equipment is a 3t free forging hammer. It is far from being able to satisfy the requirements of a 630kJ paired strike hammer for working stock. It requires the construction of a new 16000kN free forging hydraulic press;

(2) Operating devices associated with 630kJ paired strike hammers are 0.5t. They are not capable of satisfying forging production requirements. It is required to coordinate 1.5t operating devices;

(3) Various units of die forging and stock working equipment (250, 400, and 620kJ paired strike hammers, 3t free forging hammers, as well as 16000kN free forging hydraulic presses) all require coordination to be able to automatically measure temperature, record, and report alarms associated with horizontal flame combustion nozzle coal gas heating ovens;

(4) Renovating hydraulic drive systems associated with 31500kN oil presses causes pressure functions to carry out equal strain speed forging;

2. Technology Methods

(1) Begin development of isothermal die forging technology research associated with aluminum alloy and titanium alloy forged members;

(2) Begin development of large paired strike hammer precision and semi-precision forging technology research.

VI. OUTLOOK

Completing the technology reforms described above, up to the end of this century or for an even slightly longer period, the Hongyuan Forging & Casting Plant forging technology level and production capabilities, basically, are capable of satisfying the requirements of Chinese test manufacture of civilian aircraft as well as various types of military aircraft for large steel, high temperature alloy, and titanium alloy die forged members as well as medium and small size aluminum and titanium alloy precision members. The next objective, then, is the development of isothermal die forging technology associated with high temperature powder alloys, industrial forging techniques associated with die forging of large members having projection areas of over $1m^2$, as well as precision forging and semiprecision forging technology associated with large forged members, reforming equipment a step further and improving production environments.

(TOP RIGHT COL. FOREIGN PG. 18)

(PG. 19 CONTINUED)

5. With regard to hat shaped long purlin flaws pressed out hot, some companies press out flaws during pulling and bending processes, that is, on a pulling and bending device, they install a system to press out flaws toward one side. When the pulling and bending is finished, they subsequently press out the flaws. Some companies, by contrast, install a specialized device for pressing out flaws. Both methods are capable of adoption. They should be chosen based on the production situation and requirements.

6. Cold storage systems can be of many forms--cold cabinets, dry ice boxes, and so on.

To summarize the analysis above, forming technology and equipment deployment plans associated with inflection structural material parts are generally as follows:

Roll material -> cut strip material -> goes to corrugation and roll material -> solid solution heat treatment -> cold storage -> multiple axis rolled forms -> hat shaped material formation and hot pressed out flaws -> four axis rolling and bending or pulling and bending makes parts -> artificial aging -> drill hole corrections -> surface processing.

Key equipment which corresponds to this is: one strip material cutting device, one x-shaped roller corrugation device (including roll material), multiple axis roll form device (including straight and fixed length tangent cuts, CNC 4 axis rolling and bending machines or pulling and bending machines), if production amounts permit, one unit that two types of parts can use together, one unit of flaw hot pressing equipment, one unit of solid solution heat treatment equipment capable of using a 100t oil press or a 100t punching machine, one unit of artificial aging furnace 10m or over, one set of cold storage equipment, and, also add in edge cutting devices, hole drilling devices, and surface treatment equipment.

IV. A FEW SUGGESTIONS

Civilian aircraft production and foreign civilian aircraft part contract production both require the establishment in China of inflection structural material part production lines. To this end, it is suggested that:

1. On the basis of demonstrated technology plans and equipment deployment plans carried out in the organizing of relevant experts, organize execution.

2. With respect to a number of pieces of long line equipment--for example, such key equipment as CNC four axis rolling and bending devices--they should be put into developmental test production as early as possible.

3. In order to guarantee normal operations of assembly lines, one should strengthen and improve production site organization and management.

(BOTTOM OF FOR. PAGE 18)

NIOBIUM ALLOYS CAPABLE OF TOLERATING HIGH TEMPERATURE STRESSES

(Donghua)

The Teledyne Wash Chang Albany Company has developed a type of niobium alloy WC-103 (Nb-10Hf-1Ti) which is capable of satisfying high performance, light weight space flight propulsion system requirements. This type of alloy is capable of substituting for alloys with relatively low strengths, and, in conjunction with this, at the same time, maintaining required malleability and weldability. It is a type of niobium alloy with the best malleability. Moreover, it is capable of successfully bringing to bear such antioxidation coating layers as chromium silicide.

WC-103 is capable of satisfying the majority of rocket engine part requirements for operating under 1482°C. Compared to a good number of other engine materials, it saves even more weight. Due to light weight and added reliability, the result is that engine costs clearly drop. WC-103 density is 0.876kg/m^2. Thermal expansion coefficient is 8.7ppm/°C. Melting point is 2300°C - 2400°C.

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A SIMPLE ANALYSIS OF INFLECTION STRUCTURAL MATERIAL PART FORMING TECHNOLOGY AND EQUIPMENT DISPOSITION

Chang Fazhou Wang Baoren

I. APPLICATIONS OF INFLECTION STRUCTURAL MATERIAL PARTS IN CIVILIAN AIRCRAFT

As concerns inflection structural material parts associated with modern aircraft for civilian use (called simply civilian aircraft) -- in particular, inflection cap structural material and Z structural material parts--the amount of use is very great. For example, 40-45% of Boeing 737 fuselage structural material parts are inflection structural materials. Typical civilian aircraft fuselage inflection structural materials reach 61%. Among these, in long purlin parts, inflection hat shaped long purlins account for 60%. In frame type parts, Z structural inflection materials account for 81%.

These types of parts are not only used a great deal, but, due to unceasing increases in useful aircraft life, requirements for their forming quality also get higher and higher. In addition, parts dimensions are exceedingly long--the longest reaching more than 9m. For this reason, foreign plants pay very serious attention to them and have done a very great amount of research work on the forming technology and equipment, setting up specialized production lines. It goes without saying that China, at the present time, produces civilian aircraft or contracts production. This type of part is not imported, so it is only a matter of being able to produce a number of general frame type parts. How to solve the formation of inflection structural material parts has already become one of the key questions which needs to be resolved in civilian aircraft and contracting production.

II. ANALYSIS OF INFLECTION STRUCTURAL MATERIAL PART FORMATION TECHNOLOGY

From an analysis of the geometrical configuration of parts, inflected hat shaped long purlins, in the middle sections of fuselages, have mostly no section longitudinal curvature changes.

They are straight line sections. Using multiple axis rolling forms will do it. In fuselage head sections and tail sections, there are longitudinal curvature changes. There is a roughly parabolic extension. However, there is a need for multiple axis rolling forms, and exterior forms also need rolling and bending. Looking from the point of view of changes in cross sectional forms, some civilian aircraft opt for the use of equal cross sections. However, some civilian aircraft, in order to lighten weight, opt for the use of inflectional hat structural materials with changing thicknesses. These not only require rolled forms and rolling and bending, but also need mechanical working. Inflectional Z structural frames are all parts that possess different curvatures. The maximum radian is R = 1671mm. This type of part requires rolling forms, rolling and bending, or pulling and bending.

The final forming of this type of part opts for the use of forming by rolling and bending or pulling and bending. The two types of methods, at the present time, both have applications outside China. They should be determined based on the actual situation.

Reliability and useful life of civilian aircraft are the keys to modern planes. Because of this, foreign plants regard very seriously the practical function of aircraft parts, that is, each item's strength properties and useful life as well as quality control during parts manufacturing processes related to it. To this end, in the selection of parts materials, various nations all opt for the use of high strength aluminum alloys resistant to stress corrosion. For example, the U.S. opts for

the use of 7075 plate material. From the angle of utilization, one always hopes that materials possess good mechanical properties. From the angle of forming, by contrast, one hopes that materials have good forming characteristics. Resolving this pair of contradictory keys is what heat treatment configuration materials are formed in. In relevant standards, it stipulates: as far as 7075 material is concerned, when one opts for the use of a gradual entrance into rolling and bending formation, it is only permitted to work in a O state. In accordance with this stipulation, after parts are formed in a O state, one again carries out solid solution heat treatment. It is then necessary to deploy a heat treatment quenching furnace of 10m or over. What is even more important is that the amount of correction work associated with quenching deformations is very large. On the basis of statistics, it is 30-40%. With regard to linear cap structural material parts, it is possible on a correction device (or system) to correct their shapes. In the case of shape corrections of structural material parts which possess curvatures (in particular, double curvatures), this is then extremely difficult.

After 7075 material is in solid solution heat treatment (that is, quenching)--within a fixed time period--it possesses a good plasticity which is nearly better than the annealing state. This type of condition is called the new quenching state. It is also called the AQ state. However, this type of condition is not stable. Material point particles associated with soluble strengthening phases--which were originally dissolved in solid solution--with the passage of time, will gradually come out of the solid solution spontaneously. With this the case, it causes materials to gradually turn hard, and plasticity drops. Strength increases. In order to maintain this type of AQ state in materials, relevant standards stipulate 1 hour for 7075. However, at low temperatures (for example, -15°C - 25°C), this type of configuration can be maintained relatively long periods. Going through experimentation, at -15oC, it persists not over 4 days

and nights. Material property parameters still approach the AQ state.

On the basis of this special material characteristic, it is entirely possible, in the new quenching state, to form parts--that is, take semifinished product materials and, after solid solution heat treatment, put them through a multiple axis correction and flattening device for processing. Forming comes after. Or, at the production site, deploy a set of cold storage equipment, take the solid solution, heat treated material, and, immediately put it into the cold storage system. Within the stipulated time period, take it out and form it whenever necessary. As far as this type of industrial technique is concerned, it not only satisfies part forming heat treatment status requirements, but also, is capable of guaranteeing deformation resilience during forming processes and reduction in the amount of correction work.

The above is an analysis of the key industrial techniques (or work processes) in the forming of inflection structural material parts. Besides them, there are also rolled plate materials, cut strip materials, (hat shaped long purlin) hot pressed out flaws, artificial aging, drill hole corrections, surface treatments, and so on. At the moment, we will not give superfluous descriptions of them one by one.

III. EQUIPMENT DEPLOYMENT

1. Due to the fact that forming by metal inflection is a complicated system with multiple variables, various nations have done a great deal of research on the relationships between the various variables. However, they still have not completely found the patterns. Because of this, at the present time, inflected metal forming technology is still dependent, to a very great degree, on empirical experience. In view of this fact, in order to guarantee part formation quality and precision reproducibility, a clear step forward in foreign inflected metal

forming equipment is conversion to digital control of key equipment and--in such forming as pull shaping, pulling and bending, rolling and bending, and so on--universal adoption of the use of CNC controlled record and play back control systems or ordering instructional systems. Because of this, key equipment on Chinese inflection structural material part production lines, such as four axis rolling and bending devices or structural material pulling and bending devices, should all deploy CNC systems or CNC controlled record and play back systems.

2. In the case of forming equipment associated with parts from the two types of structural materials, if amounts of production permit, the forming of sets out of equipment makes it possible for two production lines to use one set of equipment together.

3. Due to the fact that the dimensions of these types of parts are excessively long, in order to avoid solid solution heat treatment equipment being excessively large and to guarantee the quality of strip material solid solution heat treatment, it is possible to use cross shaped roller corrugation generators, taking strip material and making it into a corrugated form. After rerolling to become roll material with spacing intervals, carry out solid solution heat treatment.

4. In view of foreign supplies of plate materials being provided directly from metallurgy departments as strip material in the various types of dimension specifications required and China, at the present time, still not being able to do that, it is possible to acquire one strip cutting machine.

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CHARACTERISTICS OF NONDESTRUCTIVE TESTING FOR COMMERCIAL AIRCRAFT

Yuan Zhenming

ABSTRACT

This paper briefly describes the key specifications, materials, characteristics, and requirements involved in nondestructive testing technologies such as ultrasound inspection, penetrant inspection, magnetic particle inspection, and radiographic inspection relative to commercial aircraft production.

In the production of aircraft for civilian use (simply called commercial aircraft), the materials standards, industrial technology standards, and quality control standards involved in the nondestructive inspection techniques adopted all impact penetrant inspections, magnetic particle inspections, ultrasound inspections, radiographic inspections, vortex inspections, composite material as well as cemented structure inspections, and so on. Taking these documents as the foundation, combining the statuses of the execution and implementation of these standards, the article then makes a broad analysis of the characteristics of nondestructive inspection technologies and quality control adopted in the production of commercial aircraft.

I. PENETRANT INSPECTIONS

Penetrant inspections are divided into two types--fluorescent light penetrant inspections and coloring penetrant inspections. These two types of methods both have broad applications in commercial aircraft production. In particular,

fluorescent light penetrant inspection is utilized the most and is the most universal method.

1. Fluorescent Light Penetrant Inspection

In order to guarantee fluorescent light inspection quality, first of all, it involves the materials used in inspection. It includes penetrants, emulsifiers, solvent removal agents, and developers--those 4 types. Penetrants are the most key materials used in fluorescent penetrant inspections. Table 1 sets out penetrants as well as suitable ranges adopted in the production of commercial aircraft. These penetrants should conform to the stipulated requirements of U.S. military standard MIL-I-25135, opt for the use of evaluations carried out by relevant departments, and be entered into the certified products lists of firms supplying designated trademarks. In conjunction with this, in accordance with MIL-STD-6868 stipulations, routine tests are carried out. Commercial aircraft standards recommend the use of high sensitivity water wash type penetrant, not the use of developer. Medium sensitivity (symbol C) corresponds to class I grade 2 method A in MIL-I-25135. This is capable of being used in normal inspection situations. High sensitivity (symbol D) corresponds to class I grade 3 method A in MIL-I-25135 and is used in special situations.

Developers are divided into 3 types--wet developing agents (water solution or water suspension floating types), dry developers, and nonaqueous wet developers. Inspections of large commercial aircraft parts make broad use of nonaqueous wet developers, using static electricity spraying methods to carry out inspections. After adopting their use, at times of emulsification method inspection, only then is use made of emulsifiers. With regard to emulsifier requirements, the stipulations of MIL-I-6868 should be satisfied.

TABLE 1 PENETRANT SELECTION AND APPLICATION

1	2	3
代号	渗透剂	应用范围
A	4 低灵敏度水洗型（I类，1级，方法A）	用于未机加工的铸件、锻件、焊接件和原材料检验 10
B	5 中等灵敏度后乳化型（I类，1级，方法B）	用于规定渗透检验的零件，不推荐用于大型零件，除非整个零件可自动清洗 11
C	6 中等灵敏度水洗型（I类，2级，方法A）和/或专用规范3级	凡规定渗透检验、渗漏试验均可使用 12
D	7 高灵敏度水洗型（I类，3级，方法A）和专用规范4级	飞机上检验疲劳、应力腐蚀和晶间腐蚀裂纹，可用于检验返修零件或有缺陷零件的返修部位及有规定时的特殊用途 13
E	8 高灵敏度后乳化型（I类，3级，方法B）	与代号D类相同，但零件尚未安装在飞机上时使用，乳化剂可用喷洗法清除 14
F	9 高灵敏度溶剂去除型（I类，3级，方法C）	用于检查安装在飞机上零件的疲劳、应力腐蚀及晶间腐蚀裂纹。可用以评判返修零件或有缺陷零件的返修部位的渗漏检查，及有规定时的特殊用途 15

Key to Table 1 on following page.

Key to Table 1: (1) Symbol (2) Penetrant (3) Application Range (4) Low Sensitivity Water Wash Type (class I, grade 1, method A) (5) Used in tests on cast members, forged members, welded members, and original materials which have not yet been machined (6) Medium Sensitivity Post Emulsification Form (class I, grade 1, method B) (7) Used on parts stipulating penetrant inspection. Not recommended for use on large parts, except nonintegral parts that can be washed automatically. (8) Medium Sensitivity Water Wash Form (class I, grade 2, method A) and/or Specialized Standard Grade 3 (9) All stipulated penetrant inspections and seepage tests can be used (10) High Sensitivity Water Wash Form (class I, grade 3, method A) and Specialized Standard Grade 4 (11) As far as inspections on aircraft for fatigue, stress corrosion and intercrystalline corrosion crackle are concerned, it is acceptable to use in inspections of parts returned for repair or sections of flawed parts returned for repair as well as special uses when stipulated (12) High Sensitivity Post Emulsification Form (class I, grade 3, method B) (13) Same as symbol D. However, it is used when parts have not yet been installed on aircraft. It is possible to use spray washing methods to eliminate emulsifiers (14) High Sensitivity Solvent Elimination Type (class I, grade 3, method C) (15) Used in checking fatigue, stress corrosion, as well as intercrystalline corrosion crackle in parts installed on aircraft. It can be used in order to judge parts returned for repair or sections of flawed parts returned for repair as associated with seepage tests as well as special uses when stipulated

2. Coloring Penetrant Inspections

It is only when there is no way to use fluorescent light penetrant inspections or engineering documents do not stipulate the use of fluorescent light penetrant inspection that it is then possible to use coloring penetrant inspection. Coloring /21 penetrant inspection is not capable of being used as the final inspection for space flight parts. Coloring penetrant inspection materials are divided into 3 groups: (1) is type II stipulated in MIL-I-25135 (visual coloring) and method C (solvent removal); (2) is type II stipulated in MIL-I-25135 and method B (oil affinity post emulsification); (3) is type II stipulated in MIL-I-25135 and method A (water washing type). Speaking in terms of aircraft part inspection, the second group is not used.

3. Quality Control

Controlling penetrant inspection quality is extremely important to guaranteeing the reliability of inspection results. It must run through controls of materials and equipment used in inspections as well as complete technological processes. In this regard, it must be taken very seriously. First of all is controlling materials used in inspections, strictly selecting for use stipulated grades of penetrants required for different parts and different inspections. Materials entering plants should undergo routine tests. With regard to materials in use, they must also undergo routine tests stipulated in accordance with MIL-I-6868. In the cases of new penetrants, penetrants in use, wet developers, dry developers, as well as nonaqueous wet developers, and so on, all stipulate different inspection items and requirements. As far as equipment in use in inspections--such as, black light lamps, photometers, and so on--is concerned, it all is checked at intervals stipulated. With regard to strictly controlling inspection technology, as one uses different types of penetrants on different materials and types of parts,

the penetration retention times also have different stipulations. With differences in workshop temperature, stipulated penetration retention times are also different. When option is made for the use of autoemulsifying penetrant inspection, there are concrete stipulations made for both water washing times and pressures. In order to test the effectiveness of penetrants, the stipulation team does prechecks, opting for the use of a type of specialized simple crack plastic penetration test plate, which is both economical and convenient.

II. MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection is one type of frequently used method to check ferromagnetic materials as well as their manufactured item surfaces and near surface flaws. Commercial aircraft magnetic particle inspection methods are based on such standards as military magnetic particle inspection equipment standard MIL-I-6867 and military magnetic particle inspection method standard MIL-I-6868.

1. Materials and Equipment Used in Inspection

As far as key materials associated with magnetic particle inspection are concerned, they are divided into the two large classes of black magnetic particle and fluorescent magnetic particle. It is normally recommended to use 7C black magnetic particles from the U.S. Citong (possibly Magneflux) Co. or products of other companies at a corresponding level--for example, the No.100 magnetic particles produced by the U.S. Sherwin Co. 7C magnetic particles are relatively advanced magnetic particles. In the U.S. and other countries, they are widely used. Their overall sensitivity is relatively high. The fluorescent magnetic particles recommended for use are 14A produced by the U.S. Citong (possible Magnetoflux) Co. They can be formulated with water or oil to become magnetic water

suspensions or magnetic oil suspensions, causing them to have the characteristics associated with magnetic particle inspections and fluorescent light inspections. 14A fluorescent magnetic particles also are relatively more used internationally. Their periods of water resistance and oil resistance are long. And, they are a type of magnetic particle with high sensitivity. Recently, people have carried out comparative tests on such things as magnetic characteristics, size, density, color, sensitivity, and other similar indices for 14 brands of magnetic particles which can be obtained in China. They clearly showed that 14A and 7C are, in fact, magnetic particles with good overall properties.

Recently, with regard to magnetic particle inspection standards, changes have been made--use of environmental samples to carry out tests, opting for the use of black magnetic particles or fluorescent magnetic particles, putting through a 2500A direct current. Also, the original standards required displaying 5 apertures. The altered new standards require displaying 9 apertures. It is possible to see that inspection sensitivity requirements are higher.

In accordance with the stipulations of MIL-I-6868, option is made for a horizontal wet method flaw detection device (type II). Opting for the use of a movable magnetic particle flaw detection device, by contrast, should conform to the requirements of types III, IV, and V. All of these types of equipment are three phase or two phase full wave rectifier flaw detection devices. In conjunction with this, they are only limited to using wet continuous methods. There are concrete requirements with regard to such things as maximum magnetic particle flaw detection device currents, checking the number of current control switches, as well as measurement precision, and so on.

2. Inspection Methods

Wet continuous methods are primarily inspection methods. They are applicable to the inspection of all parts except those having special stipulations. When use of standard fixed or portable flaw detection devices is limited by part shapes, dimensions, locations, or inspection zones, it is possible to use electromagnets or permanent magnets to carry out wet continuous method inspections. Residual magnetism methods are used to evaluate flaws that have already been pointed out by wet continuous methods. With regard to the inspection of the inner surfaces of tube shaped parts, which cannot be inspected by wet continuous methods, they also use residual magnetism methods. As far as commercial aircraft production is concerned, the use of fluorescent magnetic particles is recommended--in particular, for threaded and toothed parts. For surfaces which cannot be reached by ultraviolet light--for example, interior apertures, and so on--it is possible to use black magnetic particles.

3. Quality Assurance Measures

With regard to quality assurance associated with magnetic particle inspections, there are clear stipulations in all such areas as equipment, materials, technology, and personnel. Quality control is strict. There are a great many items that must be checked or tested. In the case of each item, there are checking methods and periods stipulated. As far as factors influencing flaw detection sensitivity are concerned, controls are added one by one--for example, there are periodic checks of all such things as magnetic suspension properties, magnetic field indicator devices, ultraviolet photometers, white light illumination meters, flaw detection device circuiting times, ammeter readings, short circuits, and so on. Magnetic suspension concentrations are required to be checked by each operation team once. There are periodic checks on the vision and experience

qualifications of personnel. There are also specialized agencies setting up the execution of quality supervision and carrying out checks and oversight.

III. RADIOGRAPHIC INSPECTIONS

Commercial aircraft radiographic inspection methods take as their basis MIL-S-00453B technology standards used generally in radiographic inspections. With regard to key standards, there are specialized general radiographic camera inspection principles and specialized cast member radiographic inspections. Key characteristics fall into the several areas below.

1. Materials Used in Inspections

Materials used in radiographic inspections primarily include photographic film, penetrometers, and film developing materials. Films it is permitted to select for use are shown in Table 2. The grade 1 and 2 films in the Table are normally used. It is only through getting special permission that it is possible to use grade 3 film. Grade 4 film is only suitable for use in checks on excess.

Stipulations are that radiographic photography can use 3 types of penetrometers--that is, the sheet form penetrometer stipulated in U.S. military standard MIL-S-453, the wire form penetrometer specified in ASTM E 747, and the wire form penetrometer stipulated in DIN 54-109. Due to historical causes, the custom has been to use sheet form penetrometers. China's aviation standards stipulate using wire form penetrometers. There are 6 types of materials in the penetrometers used in the production of commercial aircraft--that is, stainless steel, steel, aluminum, magnesium, copper, and titanium--selected for use in accordance with the materials which are the objects of inspection and the grades of radiographic photography.

2. Technology

Besides opting for the use of film to act as light sensitive material, it is permissible to use nonfilm methods. Detailed stipulations are made with regard to all such things as the locations of penetrometer placements and their number, film location, diascopic distance, methods of handling negatives, negative density, and flaw judgment. China's aviation standards stipulate that negative density is 1.2 - 2.5. It is normally controlled at 2.5. In the U.S., a number of companies specify it at 1.7 - 3.5. It is normally controlled at 2.5. In this way negative densities are made to lie on sections of characteristic curves with even higher average gradients, raising the contrast associated with radiographic photography.

With regard to relatively strict control of developing liquids, in accordance with different temperatures, there is strict control of different development times. Each team must use one sheet of standard exposure film in order to inspect developing liquid effectiveness. /22

TABLE 2 FILMS USED IN RADIOGRAPHIC PHOTOGRAPHY

按 ASTM 规定的等级 1	说明 2	3 建议使用范围	4 可用的部分胶片
1	5 最低速，最高衬度，最细颗粒	6 要求高质量、高灵敏度，速度是次要的场合。用于电子零件、薄金属件和型材件	Dupont NDT35; Dupont NDT45; Gevaert D2; Kodak R
	7 低速，很高衬度，很细颗粒	8 高灵敏度、高衬度和细颗粒的底片，提供高质量的射线照相。适用于低的、中等的或高电压射线照相的材料，或用于 γ 射线照相	Dupont NDT55; Gevaert D4, D5; Kodak M, T, TMX
2	9 高速，中等衬度，细颗粒	10 用相当短的曝光时间或低电压，提供高质量的射线照相。适用于低电压或高电压的 X 射线设备，或用于 γ 射线照相	Dupont NDT65, 70, 75; Gevaert D7; Kodak AA, AX
3	11 高速，中等衬度，粗颗粒	12 提供短的曝光时间，不要求高的射线照相灵敏度。适用于厚的或很厚断面的致密金属的 X 射线照相，或其它材料的 γ 射线照相或 β 射线照相	Gevaert D4; Kodak No—screen
4	13 中速，中等衬度，中等颗粒	适用于飞机或飞机组件中的外来物检查 14	Duport NDT91; Geveart Industrial Kodak XAR

Key to Table 2 on following page.

Key to Table 2: (1) Grades In Accordance with ASTM Stipulations (2) Explanation (3) Suggested Usage Ranges (4) Some Films Which Can Be Used (5) Lowest Speed, Highest Contrast, Finest Grain (6) Situations Requiring the Highest Quality, the Highest Sensitivity and in Which Speed Is of Secondary Importance. Used in Electronic Parts, Thin Metal Parts, and Structural Material Parts. (7) Low Speed, Very High Contrast, Very Fine Grain (8) High Sensitivity, High Contrast, and Fine Grain Negatives Supplying High Quality Radiographic Photography. Appropriate for Use with Low and Medium Level or High Voltage Radiographic Photography Materials or Use with Gamma Ray Photography (9) High Speed, Medium Contrast, Fine Grain (10) Using Quite Short Exposure Times or Low Voltages, Supplies High Quality Radiographic Photography. Appropriate for Use on Low Voltage or High Voltage X-Ray Equipment or Use with Gamma Ray Photography (11) High Speed, Medium Contrast, Coarse Grain (12) Supplies Short Exposure Time. Does Not Require High Radiographic Photography Sensitivity. Appropriate for Use with Low Voltage or High Voltage X-Ray Equipment or Use with Gamma Ray Photography (13) Medium Speed, Medium Contrast, Medium Grain (14) Appropriate for Use in Checking Foreign Items in Aircraft or Aircraft Assemblies

Radiographic inspections of cast members are divided into the 4 grades IA, IB, IIA, and IIB. IA is 100% inspection. IB and IIA are sampling inspections. IIB is no inspection. On the basis of radiographic inspection results, the quality of parts is also divided into 4 grades. After that, in accordance with different requirements, testing and acceptance is carried out.

IV. ULTRASOUND INSPECTION

Specialized deformation metal ultrasonic wave inspection standards are the general guiding documents associated with ultrasonic wave inspections of commercial aircraft metal materials. Partial contents have already been absorbed into later amended military standard MIL-STD-2154.

1. Instruments Used in Inspections and Contrast Test Pieces

Commercial aircraft manufacturing firms have clear requirements for the characteristics of ultrasonic wave flaw detection instruments--for example, vertical limits, up/down linear limits, sensitivity, signal to noise ratios, incident surface and back surface resolution, horizontal limits as well as horizontal linear ranges, and so on. These indices all pertain to utilization properties. With regard to test measurement methods for these properties, there are strict specifications for all of them. Operating personnel can, in accordance with the stipulated programs, carry out measurements and tests. Stipulations were also made for the selection and requirements associated with probes. The probes used should be able to supply crystal chip dimensions, effective beam widths, distance-amplitude characteristics, wave forms, and frequencies. In conjunction with this, there are requirements to carry out periodic checks on probes.

As far as specialized standards are concerned--besides planar contrast test pieces used in stipulated checks on planar parts--there are also specifications for convex and concave surface contrast test pieces, cylindrical transverse wave contrast test pieces, planar transverse wave contrast test pieces, and other relevant contrast test pieces. Clear stipulations have been made on test piece dimensions, working precision, manufacturing methods, as well as inspection methods, and so on. User departments are capable, on the basis of plan requirements, of making corresponding contrast test pieces.

2. Inspection Methods

With regard to the stipulations in MIL-STD-2154, it is possible to opt for the use of water immersion methods or contact methods to carry out inspections on parts. However, in specialized standards, stipulations only permit opting for the use of water immersion methods. Clearly, in the case of opting for the use of water immersion methods, results are even more stable and reliable.

On the basis of requirements associated with different grades of inspections, clear stipulations have been made with regard to the surface roughness of inspected parts--for example, in the case of A2 grade inspections, surface roughness does not exceed 63 RHR; A1 grade does not exceed 125 RHR; and, A, B, and C grades do not exceed 250 RHR. These types of stipulations are extremely important for guaranteeing the reliability of inspection results.

The selection of incident surfaces is most relevant to the discovery of flaws. Chosen inappropriately, it is possible to create inspection oversights. Specialized standards stipulate a requirement to scan 3 adjoining surfaces on parts with hexagonal forms. As far as round cake shaped members with thicknesses

under 50.8mm are concerned, the requirement is to carry out inspection from 3 sides.

With regard to cylinder shaped parts, tube shaped parts, as well as round cake shaped parts, a good number of stipulations associated with transverse wave inspections are all reasonable--for example, in the case of one type of turbine disc round cake shaped part, when using transverse wave probes to measure radial direction cracking, the stipulation is that one must carry out checks from the front surface and the back surface. In conjunction with this, schematic diagrams are given. In this way, they are made to have practical value. In turbine disc crack checks, due to not having carried out standards, there has been the occurrence of problems with inspection oversights.

If, in factories, there are contrast test pieces having only ϕ2.0 flat bottom apertures, then, it is possible to opt for the use of correction factors stipulated in standards to find the reflected wave heights of other flat bottom apertures. In conjunction with this, they are used in actual inspections. This type of method, theoretically speaking, has a foundation. However, during practical use, it is only when the reflecting body is placed in a distant field zone associated with probe acoustic fields, that it is possible to use them. Otherwise, they will introduce errors.

HIGH TEMPERATURE FERRIC RADICAL ALLOYS WITH EXCELLENT PROPERTIES

(Dong Hua)

For over the last 30 years, in the realm of high temperature alloys, people have primarily exerted their efforts in the development of high strength Ni radical alloys. However, with regard to ferric radical alloys associated with combustion gas turbine engine high temperature parts, by contrast, there has been almost no interest.

However, the U.S., in order to conserve shortage strategic elements, successfully test manufactured a type of Fe radical alloy with excellent properties jointly with the NASA Lewis Research Center, University of California, and United Technologies Research Center. The alloy components are: 20Cr, 20Mn, 3.2C, the rest Fe. The structural characteristics are those of arranged carbon compounds. The alloy's endurance properties can well be compared to those of the famous MAR-M200 (DS) (Ni radical), MAR-M509 (Co radical), and CRM-6D (Fe radical).

FOREIGN PAGES 23-30 MISSING FROM ORIGINAL FOREIGN TEXT.

STUDY OF GALVANIC CORROSION BETWEEN COMPOSITE MATERIALS AND 30CrMnSiA

Lu Feng Ma Yijun

ABSTRACT

Through electrochemical measurements, salt spray tests, alternate immersion tests, mechanical and fatigue property measurements and tests, as well as stress corrosion tests, research was done on galvanic corrosion characteristics associated with carbon fiber epoxy composite materials and 30CrMnSiA steel. The results clearly showed that severe galvanic corrosion exists between 30CrMnSiA steel and carbon fiber epoxy composite materials. However, there is no influence on the stress corrosion properties of 30CrMnSiA. In the article, protective measures are also given to prevent galvanic corrosion of carbon fiber epoxy composite materials and 30CrMnSiA.

Key Words: Galvanic Corrosion, Graphite Epoxy Composite Materials

I. FORWARD

Graphite epoxy composite material, designated below as simply GECM, is a new type of engineering material which has gained broad applications in recent years. Compared to ordinary metal materials, the outstanding advantages are light weight, high specific strengths and specific solidities, and long fatigue life. As a result of this, it possesses a prospect for broad applications [1]. In GECM, due to the carbon fibers that exist, the electrochemical properties are similar to those of noble metals. In the majority of electrolytes, they possess relatively positive electrode potentials. When they come in contact with

metal materials that have relatively negative electrical potentials, it will lead to severe galvanic corrosion, causing metal corrosion speed to clearly increase.

In the last 20 years, developed countries have carried out a great deal of research on galvanic corrosion produced by opting for the use of GECM, putting forward a number of preventive measures to stop galvanic corrosion produced by GECM [2,3]. Following along with this, applications of GECM in China are increasing daily, in particular, in the area of the aerospace industry. In order to lighten total aircraft weights to the greatest extent possible and to improve aircraft performance, GECM has already successfully replaced metal materials in the manufacture of certain aircraft parts. Therefore, earnest study should be given to galvanic corrosion between GECM and metals.

This article goes through electrochemical measurements and tests, speeded up indoor corrosion tests, performance tests, and stress corrosion tests. In depth research was carried out on galvanic corrosion characteristics between GECM and 30CrMnSiA. In conjunction with this, protective methods were given to prevent this type of galvanic corrosion.

II. TEST MATERIALS AND METHODS

1. Test Materials and Samples

GECM trademarks are T300/AG80. Thicknesses are approximately 2mm. They are worked to become electrochemical measurement samples and even joint samples of 30CrMnSiA contact. Water and sandpaper are used to grind off surface resin layers.

30CrMnSiA is approximately 2mm plate material. Its chemical constituents are set out in Table 1. It is worked to become electrochemical measurement samples, tensile samples, fatigue samples, and stress corrosion samples. Steel samples are taken along the rolling direction. Material heat treatment systems are 890°C quenching for 15 min and 510°C tempering for 2h.

TABLE 1 CHEMICAL CONSTITUENTS OF 30CrMnSiA

1	元素	C	Mn	Si	S	P	Cr	Ni
2	含量,%	0.28 ~0.35	0.80 ~1.10	0.90 ~1.20	≤0.030	≤0.030	0.80 ~1.10	≤0.40

Key: (1) Element (2) Amount Contained

2. Test Methods

Electrochemical measurements: Opting for the use of zero resistance technology to measure galvanic couple electric currents [4], use is made of constant electrical potential instruments to act as zero resistance meters. 3.5% NaCl water solution is the corrosion medium. Temperature is controlled at 30 ±1°C. Continuously for 24 h, galvanic couple currents are recorded for GECM/30CrMnSiA. /32

Measurements are taken respectively for the open circuit potentials of GECM and 30CrMnSiA in order to precisely determine the degree of electrochemical differences between the two, that is, the size of electrical potential differences.

Indoor accelerated corrosion test methods: After taking 30CrMnSiA and GECM and making even joints between them or respectively adopting different protective measures, carry out

salt spray tests or alternate immersion tests. Salt spray tests are carried out in accordance with ASTM test method B117-73. Alternate immersion tests are carried out in accordance with the aviation industry standard HB5194-84.

Properties tests: After putting 30CrMnSiA and GECM in contact, going through salt spray or alternate immersion corrosion tests, take out the coupled GECM and remove the corrosion products. Carry out tensile and fatigue tests. Measure such values as strengths, percentage elongation, fatigue life, and so on. Tensile tests are carried out in accordance with HB5143 ((Metal Room Temperature Tensile Test Methods)). Fatigue tests are carried out in accordance with GB3075 ((Metal Material Axial Loading Fatigue Test Methods)).

Stress corrosion tests: Opting for the use of slow strain speed stress corrosion tests, study the influences of galvanic corrosion between GECM and 30CrMnSiA on 30CrMnSiA stress corrosion properties. Tests are carried out in accordance with institute standard Q/6S 416-84.

III. RESULTS AND DISCUSSION

1. Electrochemical Measurements

Respectively measure the open circuit potentials for GECM and 30CrMnSiA. The larger the potential difference is between the two, the larger is the tendency to produce galvanic corrosion. The open circuit potentials measured in 3.5% NaCl solution are shown in Fig.1. The potential stabilization of 30CrMnSiA is relatively fast. GECM electrodes are monoxyreduction electrodes. The diffusion of oxygen is relatively slow. The time for reaching stability is relatively long. Potential differences between GECM and 30CrMnSiA are close

to 1V. This potential difference acts as motive force to make 30CrMnSiA function as the positive electrode to produce corrosion.

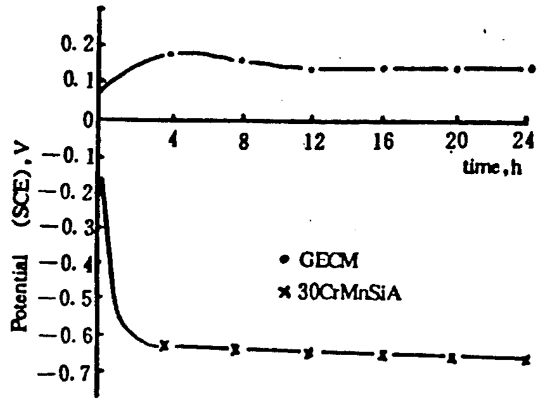

Fig.1 Potential-Time Relationship Curves

In Table 2, the galvanic couple currents measured in 3.5% NaCl solution for GECM and 30CrMnSiA are given as well as weight loss values for 30CrMnSiA tests after going through 24hr testing. Test results can be seen in Table 2. Galvanic couple currents, weight loss values, and so on, between GECM and 30CrMnSiA are all relatively large. 30CrMnSiA surface corrosion is severe. This clearly shows that GECM has a very large influence on 30CrMnSiA galvanic corrosion. After completing tests, a clearly corroded layer was removed from sample surfaces. In solution, there were a great many corrosion products in existence. When solutions were stirred, galvanic couple currents between 30CrMnSiA and GECM increased. Weight loss values increased. Galvanic corrosion

TABLE 2 GALVANIC COUPLE CURRENT AND WEIGHT LOSS VALUES MEASUREMENT RESULTS (30℃/24h)

偶接 GECM 1 材料	2 平均电偶电流密度, μA/cm²	3 失重值 μg/cm²	4 表面状态
30CrMnSiA	24.2	500	表面腐蚀均匀，呈黑色，有棕褐色产物 5
30CrMnSiA*	56.0	1250	腐蚀加重，棕褐色产物增多 6

*搅拌溶液 7

Key: (1) Even Joint GECM Material (2) Average Galvanic Couple Current Density (3) Weight Loss Values (4) Surface Configuration (5) Surface Corrosion Uniform. Presents Black Color. There Are Brown Colored Products. (6) Corrosion Increases in Severity. Brown Colored Products Increase. (7) Stirred Solution

became even more severe. Stirring quickened material transmission processes, causing material worn off the periphery of electrodes to be able to achieve immediate replacement. Accumulated materials were able to immediately disperse. With regard to the corrosion battery constituted from GECM and 30CrMnSiA, the process at the negative electrode on the GECM is:

$$O_2 + 2H_2O + 4e \longrightarrow 4OH^- \qquad (1)$$

Stirring is capable of speeding up oxygen diffusion speed in solutions, making oxygen able to reach electrode surfaces as fast as possible. Replacement, due to electrode reactions and oxygen losses, impels faster execution of corrosion processes. At the same time, it also impels positive ions produced by positive electrode reactions to go through diffusion as fast as possible

and leave electrode reaction areas, speeding up the execution of positive electrode processes.

2. Indoor Accelerated Corrosion Test and Property Measurement Results

Taking 30CrMnSiA and GECM and, under different surface treatment configurations, respectively making contact, salt spray tests or alternate immersion tests were separately carried out. After testing, changes in external appearance were recorded. In conjunction with this, tensile test samples and fatigue test samples were respectively taken and property measurements were carried out in order to precisely determine influences due to GECM galvanic corrosion on 30CrMnSiA strength, percentage elongation, as well as fatigue life. Test results are set out in Table 3 and Table 4 respectively. When 30CrMnSiA and GECM are in direct contact, after going through salt spray or alternate immersion corrosion, operating sections are severely corroded. Test samples become thin. There are obvious large pits. This will severely influence the mechanical properties of 30CrMnSiA. After adopting certain protective measures--for example 30CrMnSiA plated with Zn and, afterward, coated with HO6-2 paint, GECM coated with HO6-2 paint, or GECM surfaces all fixed with a layer of polyvinyl chloride film, then, using sealing glue to seal the edges, and finally adding another coating of HO6-2 paint--it is possible to effectively prevent galvanic corrosion between the two.

Looking at the results of strength and percentage elongation tests, comparing test samples of 30CrMnSiA even jointed to GECM and test samples of 30CrMnSiA not even jointed to GECM, after salt spray tests for 1440h, strength and percentage elongation had respectively fallen 38.0% and 61.1%. Under alternate immersion test conditions for 1440h, drops in strength and percentage elongation were, respectively, 3.2% and 17.2%. Here,

we are not able to take test samples after salt spray tests or alternate immersion tests and compare them to uncorroded blank test samples. It is only possible to compare, under the same type of corrosion test conditions, the influences of even jointed GECM and noneven jointed GECM on 30CrMnSiA properties. The reason is that, when comparing GECM galvanic corrosion, fixing as much as possible other influencing factors, consideration is only given to the effects given rise to by this one GECM factor.

On the basis of the fatigue life test results of Table 4, when σ_{max}= 800MPa, after 1440h of salt spray corrosion of 30CrMnSiA/GECM test samples, 30CrMnSiA test samples were severely corroded. Dimensions were reduced. The strength basically did not reach 800MPa. At this stress level, fatigue life was zero. After 1440h of alternate immersion corrosion, the fatigue life, compared to test samples of noneven jointed GECM, dropped 46.2%. This clearly shows that GECM has an extremely large influence on the fatigue life of 30CrMnSiA. After adopting protective measures, the overall fatigue life cycle number is greater than 10^5.

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TABLE 3 EXTERIOR APPEARANCE TEST RESULTS AND PROPERTY MEASUREMENT RESULTS AFTER 30CrMnSiA AND GECM INDOOR ACCELERATED CORROSION

	1 表面处理及接触状态	2 腐蚀种类及时间 (h)	3 30CrMnSiA 外观结果	4 强度 (MPa)	5 延伸率 (%)
6	30CrMnSiA 不腐蚀			1155	15.1
	30CrMnSiA	7 盐雾 1440	严重腐蚀，试样减薄 8	956	5.4
	9 30CrMnSiA 偶接 GECM	7 盐雾 1440	严重腐蚀，试样减薄很明显，有大坑出现 10	592	2.1
	11 30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+H06—2 漆	7 盐雾 1440	12 无腐蚀	1154	13.0
13	30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+玻璃布+封边+H06—2 漆	7 盐雾 1440	12 无腐蚀	1160	14.8
	30CrMnSiA	14 周浸 1440	严重腐蚀，试样减薄 15	965	6.4
	30CrMnSiA 偶接 GECM 9	14 周浸 1440	严重腐蚀，试样减薄明显 16	934	5.3
17	30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+H06—2 漆	14 周浸 1440	漆面鼓泡，基体基本未腐蚀 18	1143	11.4
19	30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+玻璃布+封边+H06—2 漆	14 周浸 1440	20 漆面鼓泡，基体基本未腐蚀	1155	13.3

Key to Table 3 on following page.

Key to Table 3: (1) Surface Treatment and Contact Status (2) Corrosion Type and Time (3) 30CrMnSiA Exterior Appearance Results (4) Strength (5) Percentage Elongation (6) Not Corroded (7) Salt Spray (8) Severe Corrosion. Test Samples Thinned Out. (9) 30CrMnSiA Even Jointed with GECM (10) Severe Corrosion. Test Sample Thinning Very Obvious. Appearance of Large Pits. (11) 30CrMnSiA Plated with Zn + HO6-2 Paint Even Jointed to GECM+HO6-2 Paint (12) No Corrosion (13) 30CrMnSiA Plated with Zn + HO6-2 Paint Even Jointed with GECM + Polyvinyl Chloride Film + Sealed Edges + HO6-2 Paint (14) Alternate Immersion (15) Severe Corrosion. Test Samples Turned Thin. (16) Severe Corrosion. Test Sample Thinning Obvious. (17) 30CrMnSiA Plated with Zn + HO6-2 Paint Even Jointed with GECM+HO6-2 Paint (18) Painted Surface Swollen and Spongy. Foundation Basically Uncorroded. (19) 30CrMnSiA Plated with Zn + HO6-2 Paint Even Jointed with GECM + Polyvinyl Chloride Film + Sealed Edges + HO6-2 Paint (20) Painted Surface Swollen and Songy. Foundation Basically Uncorroded.

3. Stress Corrosion Test Results

Taking 30CrMnSiA and, respectively, carrying out tests under the three environmental conditions below: inert medium (A5 molecular sieve), 3.5% NaCl solution, and even jointed GECM in 3.5% NaCl solution--test results are set out in Table 5. At the same time, we also can advance a step further calculations of relative cracking energies associated with various groups [5]. Plastic Relative Cracking Energy:

$$\frac{E\ (3.5\%\mathrm{NaCl})}{E\ (\text{隋性})}=\frac{64.97}{66.35}=98\%$$

$$\frac{E\ (3.5\%\mathrm{NaCl}+\mathrm{GECM})}{E\ (\text{隋性})}=\frac{60.79}{66.35}=92\%$$

Local Relative Cracking Energy:

$$\frac{E\ (3.5\%\mathrm{NaCl})}{E\ (\text{隋性})}=\frac{36.56}{38.04}=96\%$$

$$\frac{E\ (3.5\%\mathrm{NaCl}+\mathrm{GECM})}{E\ (\text{隋性})}=\frac{36.37}{38.04}=96\%$$

From the calculation values described above, it is possible to see that the values of the relative cracking energies are all greater than 75%. This clearly shows that, after 30CrMnSiA is in 3.5% NaCl solution as well as being even jointed with GECM in that solution, there is a trend toward no clear influences on 30CrMnSiA stress corrosion.

TABLE 4 FATIGUE SAMPLE CORROSION TEST RESULTS AND FATIGUE LIFE RESULTS (Stress Level σ_{max} = 800MPa, f = 20Hz, R = 0.1)

1 表面处理及接触状态	2 腐蚀种类及时间 (h)	3 30CrMnSiA 外观结果	4 总循环次数 N (次)
5 30CrMnSiA 不腐蚀			$>10^5$
30CrMnSiA	6 盐雾 1440	严重腐蚀，试样减薄 7	5326
30CrMnSiA 偶接 GECM 8	6 盐雾 1440	严重腐蚀，几乎断裂 9	0
10 30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+H06—2 漆	6 盐雾 1440	11 无腐蚀	$>10^5$
12 30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+玻璃布+封边+H06—2 漆	6 盐雾 1440	11 无腐蚀	$>10^5$
30CrMnSiA	13 周浸 1440	严重腐蚀，试样减薄 14	5352
30CrMnSiA 偶接 GECM 8	13 周浸 1440	严重腐蚀，几乎断裂 15	2880
30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+H06—2 漆 10	13 周浸 1440	漆面鼓泡，基体基本未腐蚀 16	$>10^5$
12 30CrMnSiA 镀 Zn+H06—2 漆偶接 GECM+玻璃布+封边+H06—2 漆	13 周浸 1440	漆面鼓泡，基体基本未腐蚀 16	$>10^5$

Key to Table 4 on following page.

Key to Table 4: (1) Surface Treatment and Contact Status (2) Corrosion Type and Time (3) 30CrMnSiA Exterior Appearance Results (4) Total Cycle Iteration Number (5) Not Corroded (6) Salt Spray (7) Severe Corrosion. Test Samples Turn Thin. (8) 30CrMnSiA Even Jointed with GECM (9) Severe Corrosion. Almost Cracked. (10) 30CrMnSiA Plated with Zn + HO6-2 Paint Even Jointed with GECM + HO6-2 Paint (11) No Corrosion (12) 30CrMnSiA Plated with Zn + HO6-2 Paint Even Jointed with GECM + Polyvinyl Chloride Film + Sealed Edges + HO6-2 Paint (13) Alternate Immersion (14) Severe Corrosion. Test Samples Turned Thin. (15) Severe Corrosion. Almost Cracked. (16) Paint Surface Swollen and Spongy. Foundation Basically Not Corroded.

TABLE 5 30CrMnSiA STRESS CORROSION TEST RESULTS

2 测试项目 1 试验环境	3 规定位移率 (mm/h)	4 塑性断裂能 (J/cm³)	5 局部断裂能 (J/cm³)	6 断裂时间 (min)
7 惰性介质	0.465	66.35	38.04	493.3
8 3.5%NaCl 溶液	0.465	64.97	36.56	480.7
9 3.5%NaCl 溶液 偶接 GECM	0.465	60.79	36.37	470.0

10 注：温度为26℃

Key: (1) Test Environment (2) Measured Item (3) Stipulated Rate of Displacement (4) Plastic Cracking Energy (5) Local Cracking Energy (6) Cracking Time (7) Inert Medium
(8) Solution (9) 3.5% NaCl Solution Even Jointed with GECM
(10) Note: Temperature is 26°C.

Besides this, high strength steel stress corrosion is generally due to hydrogen brittleness. However, on GECM, the reaction produced is one of oxygen reduction $O_2+H_2O+4e \rightarrow 4OH^-$. The reaction does not involve the introduction of hydrogen. Therefore, GECM has no influence on the stress corrosion properties of 30CrMnSiA.

IV. CONCLUSIONS

1. Electrochemical research clearly shows that mutual contact between

(continued on page 39)

RESEARCH ON INDUSTRIAL PROCESSES ASSOCIATED WITH LARGE COMPOSITE MATERIAL BOX SHAPED MEMBERS

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Dong Yunming Ni Ronggen

Opting for the use of silicon rubber soft molded integral concurring formation techniques, in China, the first test production of large box section bulkheads with complex structures and difficult molding technologies was done. In the work in question, execution was carried out of research on mould design, layer adjustment, sealing slot location selection, utilization of foam adhesives, and similar items in order to make test produced large box section bulkheads conform to design requirements.

I. INTRODUCTION

The large box section bulkhead test members produced in the operations in question were 5 small boxes connected together. The structures were complex, and, in conjunction with that, there was a requirement for a manufactured member molded by one time concurring. In the vicinity of the outer surfaces of upper and lower belly plate flanges, in each case, there was a sealing slot with strict dimensional requirements. Moreover, these members must fit into connections with upper and lower wall plates and other bulkheads. Exterior dimensions as well as outer surface quality requirements are strict. Because of this, this manufactured member is a large box shaped item of complex structure and very difficult molding technology, test manufactured in China for the first time.

Chosen for use were silicon rubber soft mould open molding hot press container forming technologies, using silicon rubber soft molds to act as male molds and composite molds manufactured from steel to act as female molds. Solutions were

found for phenomena which easily appear in bridge building and crumpling and had already appeared in the pressure manufacturing of box shaped members. In conjunction with this, going through layer adjustment, the quality of member sealing slots was guaranteed, causing the manufactured items which were test produced to attain design requirements.

II. TEST SECTION

1. Dimensions and Forms of Manufactured Items

A structural schematic of the manufactured items in question is shown in Fig.1.

2. Key Materials

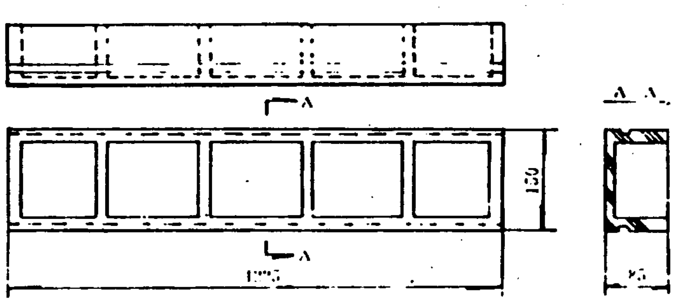

Fig.1 Schematic Diagram of Composite Material Bulkhead Structure

(1) Silicon rubber: used in making core molds, produced by the U.S. Airtech Company, trademark is Aircast 3700;

(2) Pre-immersed material: manufactured item raw material, produced by the institute in question, trademark is 5222/T300;

(3) Foam adhesive: fills up the corners of manufactured items, produced by the institute in question, trademark is SY-P1.

3. Equipment

(1) Electrically heated constant temperature vacuum drying boxes: remove gas bubbles when the vacuum is created before silicon rubber is poured;

(2) Hot pressing containers: used in the molding of composite material manufactured items.

4. Molds

Molds are divided into two sets: one set is silicon rubber core mould piece forming molds, one set is bulkhead plate forming molds.

(1) Silicon rubber core mould piece forming molds are composite molds manufactured from aluminum (see Fig.2) used in pouring silicon rubber core mould pieces.

(2) Bulkhead plate forming molds are composite molds manufactured from steel (for example, as shown in Fig.3). They are composed of two mould end plates, two mould side plates, and one mould bottom plate. During the processes of molding technologies, due to the fact that thermal expansion coefficients of molds and composite material manufactured items are different, the dimensions of the final manufactured items will be larger than the corresponding dimensions of molds. With regard to small manufactured items, this type of difference in dimensions is small to the point of being able to be ignored in calculations. The length of the manufactured items in question is 1225mm. When designing molds, it is necessary to consider making mould lengths smaller by delta L than manufactured item lengths required by blueprints. This length change can be calculated using the formula below:

$$\Delta L = L\,(\alpha_s - \alpha_c)\,(T_m - T_0)$$

In this, L - manufactured item design length

α_s- thermal expansion coefficient of steel

α_c- thermal expansion coefficient of orthogonal composite materials

T_M- composite materials molding temperature

T_o- room temperature.

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Taking the relevant data and substituting into the equation above, ΔL is approximately 2mm. In this way, mould length should be designed to be approximately 1223mm.

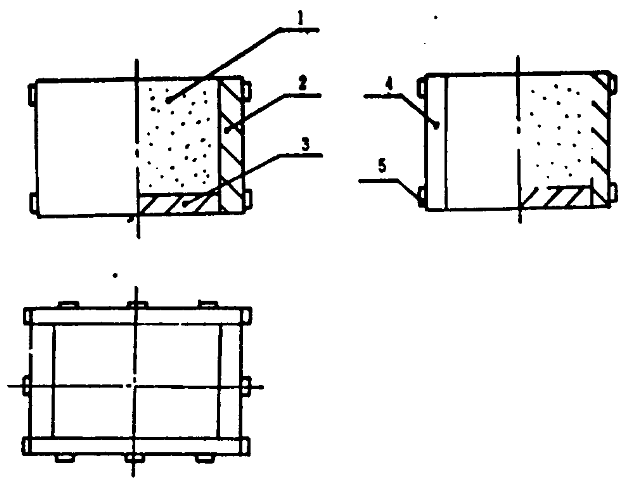

Fig.2 Silicon Rubber Core Mould Piece Forming Mould Composite Schematic

Key: 1. Core Mould Piece 2. Mould End Piece 3. Mould Bottom Piece 4. Mould Side Piece 5. Screw

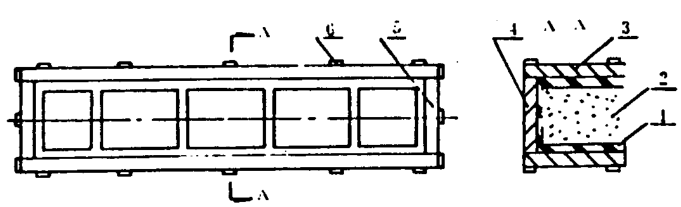

Fig.3 Bulkhead Plate Forming Mould Composite Schematic

Key: 1. Bulkhead Plate 2. Core Mould Plate 3. Side Mould Plate 4. Bottom Mould Plate 5. Mould End Plate 6. Screw

5. Foam Adhesive Layer Placement

After laying down half the total number of complete layers, using SY-P1 foam adhesive, a layer is put down on the four corners of bulkhead plate flanges. In this way, it is possible to avoid, after molding, unreliable loosening at the corners due to bridging--even extending to such problems as the production of holes through.

6. Pressing of Sealing Slots

Sealing slot requirements in the manufactured items in question are very strict. In order to properly press slots, primarily, the two measures below are adopted:

(1) Selection of Slot Locations

Due to the fact that slots are too close to belly plates, the quality of pressed slots is not good. Because of this, the distance between slots and belly plates must be greater than the thickness of belly plates.

(2) Layering Adjustment

The layering of the manufactured items in question was originally designed to be carbon film layering. However, through experimentation, it was clearly demonstrated that, using carbon film to act as layering, it is not possible to press out slots to design requirements. Going through an exchange of layering materials, and, in conjunction with that, after repeated adjustments of layer design, optimum layering materials and layering orders were selected. Pressing out slots that conform to design requirements, it was possible to satisfy assembly demands.

7. Bulkhead Plate Assembly

Using bulkhead plate stock material which is layered from pre-immersed materials, dimensions must be larger than interior mould cavities. Assembling molds is extremely difficult. It is necessary to adopt precompression to do it.

8. Bulkhead Plate Container Mounting

After assembly, molds are taken and put onto hot press container vacuum platforms to carry out vacuum bag assembly. The assembly structure is as seen in Fig.4.

9. Solidification Technology

(1) Under 0.095 MPa vacuum pressure, using a speed of 1.5°C/min, go up from room temperature to 120°C;

(2) At 120°C, pressurize 0.5 MPa, and, in conjunction with that, continue to go up to 180°C;

(3) At 180°C, hold the temperature and pressure for 2h;

(4) Discharge the vacuum, and let temperature and pressure drop naturally.

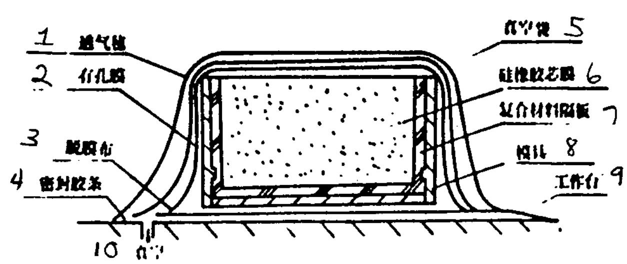

Fig.4 Bulkhead Plate Hot Press Container Schematic

(1) Gas Permeable Felt (2) Perforated Membrane (3) Film Removal Sheet (4) Sealing Adhesive Strips (5) Vacuum Bag (6) Silicon Rubber Core Mould (7) Composite Material Bulkhead Plate (8) Mould (9) Working Platform (10) Vacuum

III. PROBLEM ANALYSIS AND DISCUSSION

1. Mould Selection

There is a direct relationship between mould selection and requirements associated with manufactured items. As far as test manufactured large box section bulkhead plates are concerned, there are severe requirements in all such areas as dimensions, sealing slots, exterior surface dimensions, and so on. Using a female mould to do forming, it is possible to strictly control the exterior shape and structural dimensions of manufactured items as well as surface quality. Moreover, molds are simple, and unloading molds is easy. Because of this, we opted for the use of female molds to do forming. In addition, because the interior sections of manufactured items are 5 small boxes, interior surface requirements are not strict. Because this is the case, in order to make side surface pressures uniform, option was made for the use of soft silicon rubber expansion molds to act as male molds. Actualization demonstrated that opting for the use of these types of molds is appropriate for box shaped items with strict requirements in regard to outer surface dimensions and the forming of structures that are relatively complex.

2. The Influence of Layering on Sealing Slots

Slot widths associated with the manufactured items in question are only 6.5mm. The depth is only 2mm. It is not possible, through layering, to lay down slots in advance. However, they are hard pressured out of flat layer surfaces close to molds. Because this is the case, the status of layering has a very great influence on the quality of slots. In the research in question, many experiments were made in quest of optimum layering configurations, to make the slots from pressure molded formation totally in compliance with design requirements.

3. Laying Down Foam Adhesive

In formation processes, the 4 corners of manufactured item flanges are not capable of being completely tightened down due to layering overlap. Moreover, after layering is completed, at the corners, layering does not form 90° angles, but is circular arc shaped. Therefore, although soft molds expand, due to the fact that layering close to soft molds has already gone through taut stretching, forming bridging, pressure transmitted by soft molds is not added to layering distant from soft molds. Because of this, at corners, pressure is not, then, felt. However, in layering, after the addition of foam adhesive, the pressure produced by bubbling near foam adhesive is capable of making each layer in layering at corners add pressure, guaranteeing quality at manufactured item corners.

IV. CONCLUSIONS

1. The operations in question opt for the use of silicon rubber soft mould open molding hot press container integral formation technology. They manufactured large box section bulkhead plate members in compliance with design requirements, demonstrating that this technology is completely feasible with regard to molding this type of box shaped item.

2. As far as large box shaped members are concerned, when option is made for the use of steel molds to act as female forming molds, it is necessary to rationally adjust mould dimensions. Only then is it possible to manufacture items in conformity with design measurements.

3. Through changing layering and selecting sealing slot locations, it is possible to use molds to directly press out sealing slots in conformity with design requirements.

4. With regard to adding a layer of SY-P1 foam adhesive between layers at the 4 corners of bulkhead plates, it is possible to avoid layer bridging at corners, guaranteeing the quality of manufactured item corners.

FOREIGN PAGES 36-42 ARE MISSING FROM ORIGINAL FOREIGN TEXT.

OXIDATION AND PROTECTION OF CARBON/CARBON COMPOSITES

Chu Shuangjie Qiao Shengru Yang Zheng Liu Yinglou

Oxidation sensitivity of carbon/carbon composite materials limits their applications. In order to satisfy future needs for high temperature structural materials in such things as aerospace flight craft, it is necessary to thoroughly resolve the oxidation protection problems of carbon/carbon composite materials. This article, on the foundation of an earnest analysis of carbon/carbon composite material oxidation processes, fully summarizes ways of raising the oxidation resistance of carbon/carbon composite materials. The concrete methods include: improvement of structures, fibers, and substrates inside materials as well as using various types of methods to add protective coating layers to their surfaces. At the same time, discoveries were taken a step further. One type includes a multilayer coating system with borate glass acting as an internal coating layer and using SiC, Si_3N_4, SiO_2, and so on, functioning as outer coating layers. This is capable, at 1700°C or less, of supplying relatively good protection for carbon/carbon composite materials.

Keywords: carbon/carbon composites, oxidation inhibiting coating

I. INTRODUCTION

Carbon/carbon composite materials (simply called C/C) are carbon fiber strengthened materials with carbon substrates. They were developed in the 1960's and are, at present, the most ideal high temperature resistant materials. This type of composite material possesses both the inertness of carbon and the high strength of carbon fibers. Under conditions reaching as high as 3027°C, other materials have long since been melted. However,

C/C composite materials are still capable of maintaining their strength. This cannot be matched by other structural materials--for example, resin based composite materials, metal based composite materials, and ceramic materials. The development of C/C composite materials is a key realm in today's high technology. The various advanced nations of the world are all sparing no effort to study it. Due to the fact that C/C composite materials possess a good number of outstanding characteristics such as high relative strength, high specific moduli, resistance to high temperatures, resistance to corrosion, and so on, it leads to their broad application in space flight, aviation, atomic energy, communications, construction, sports, medical treatment, and other similar industrial realms. However, all the numerous excellent characteristics of C/C composite materials can only be maintained in inert atmospheres. Because, in air, carbon will oxidize above 450°C, oxidation reactions given rise to by very small amounts of burning loss will make C/C composite material physical properties and mechanical properties fall. C/C composite material oxidation sensitivity limits their applications. In order to satisfy future demands for high temperature structural materials in such things as spacecraft, it is necessary to resolve oxidation protection problems associated with C/C composite materials.

II. C/C COMPOSITE MATERIAL OXIDATION PROCESSES

1. C/C Composite Material Oxidation Processes

In order to improve oxidation resistance properties of C/C composite materials, it is necessary to make clear C/C composite material oxidation processes and find the weak links in order to facilitate adopting effective measures to prevent C/C oxidation.

Speaking in terms of chemical burning losses, carbon, at certain temperatures, (generally recognized to be above 450°C) reacts with oxygen to produce CO and CO_2. The larger the

concentration of oxygen in the environment is (the oxygen partial pressure), the larger the carbon surface area is, and the higher the ambient temperature is, the larger are the forces propelling oxidation reactions, and the faster chemical reactions are carried out. This is also true of C/C composite materials. However, C/C composite materials are made up of carbon fibers and substrate carbon. Oxidation processes are necessarily related to the composition and properties of carbon fibers and substrate carbon. C/C is also a type of structural material. Strengthening forms adopted with carbon fibers acting as strengthening agents (two dimensional, three dimensional, or multidimensional) as well as structural hole distributions, boundary layer binding status, and the existence of micro flaws all also influence the oxidation processes. /44

According to reports in reference [1], among unidirectional C/C composite materials made from carbon fibers and chemical vapor deposit (CVD) carbon, CVD carbon resists oxidation even more than carbon fibers. It is possible the cause is trace elements contained in carbon fibers (such as Fe, Zn, Cu, and so on) which accelerate oxidation. However, due to fiber longitudinal surfaces covering CVD carbon substrate, they are more stable than fiber ends. Because of this, oxidation often begins from fiber ends. In conjunction with this, following along with the gradual loss of fiber, it develops depth in a longitudinal direction. Only when the amount of "tunnel" type holes increases to a certain extent, does CVD carbon begin to oxidize. At the same time, reference [2] reports that, among CVD two dimensional C/C composite materials, relatively small film covered areas occupied by fiber ends resist oxidation more than very large surface areas occupied by fiber ends and not film covered. This all demonstrates the fact that CVD carbon resists oxidation more than carbon fibers.

Besides this, people going through observations of three dimensional C/C oxidation burning loss processes discovered that burning losses between fiber bundles and substrate carbon are nonsynchronous [3]. Generally speaking, deposit carbon and resin carbon are relatively resistant to oxidation. Carbon fibers (particularly, bad quality carbon fibers) do not resist oxidation. Speaking in terms of carbon fiber bundles, carbon fiber bundles parallel to the direction of gas flow will also resist oxidation and resist erosion more than carbon fiber bundles perpendicular to the direction of gas flow. In terms of micro analysis, in the interior of carbon fiber bundles, burning losses associated with single strand fibers and substrate carbon filling up their peripheries are not synchronous. The states of oxidation burning losses follow differences in raw materials and vary. If substrate carbon is resin carbon, by contrast, single strand carbon fiber oxidation burning losses in carbon fiber bundles are relatively fast, and they do not resist oxidation as well as substrate carbon surrounding single strand fibers. At the same time, more advanced research discovered [3] that, in the case of all C/C materials, phenomena associated with the precedence order of boundary surface sites and hole cracking sites were very clear. This type of priority order of burning loss and cracking expansion, in conjunction with each other, extends toward the interior with the result of producing secondary surface oxidation. This type of nonsynchronous thermochemical burning loss in various components creates independent emergences as well as strength drops brought on by secondary surface oxidation. Both of these create conditions for the production of C/C composite material mechanical erosion.

2. Oxidation Processes in C/C Composite Materials Having Protective Coating Layers

As far as the oxidation processes of C/C composite materials having protective coating layers are concerned, besides being

related to oxidation patterns of materials themselves, they clearly are also closely related to factors such as the properties of coating layers, the binding of boundary surfaces between coating layers and substrates, as so on. With regard to the addition of a protective external layer, substrate oxidation includes the several steps below, as shown in Fig.1 [4]. The first step is gas diffusion on boundary layer boundary surfaces. The second step is gas diffusing through protective layer cracks. The third step is diffusion of gases through protective layer coacervation phases. The fourth step is gases reaching substrate and reacting with oxidation protective layer boundary surfaces to form oxidation products.

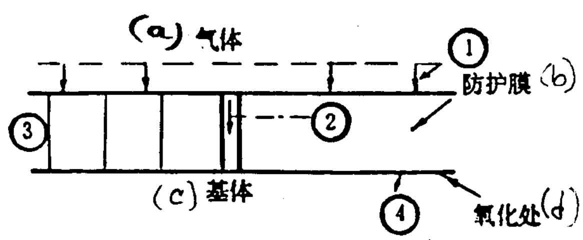

Fig.1 Schematic Diagram of Oxidation Steps

(1) Gas Diffusion on Boundary Layers (2) Gas Diffusion Through Cracks (3) Gas Diffusion Toward Coacervation Phases (4) Reactions on Boundary Surfaces (a) Gas (b) Protective Film (c) Substrate (d) Oxidation Site

In a steady state, the speeds of the first, third, and fourth steps are the same, controlling the entire substrate oxidation except the several steps associated with reacting gases and substrate oxidation. This also includes the formation of CO and CO_2 gases and their movement to the outside.

It can be seen from this that, in the case of protective coating research, high temperature oxidation resistance in regard to C/C composite materials is a key step.

III. CONCRETE WAYS TO PROTECT C/C COMPOSITE MATERIALS FROM OXIDATION

Ways of improving technology associated with C/C composite material oxidation resistance properties include the improvement of fibers, substrates, and structures and many types of means such as the application of antioxidation ceramic coating layers to C/C material surfaces. These are introduced separately below.

1. Interior Protective Methods

(1) Improved Carbon Fiber Antioxidation Properties [3]

As far as raising the quality of carbon fibers is concerned, opting for the use of graphite fibers or antioxidation carbon fibers are both capable of improving C/C antioxidation properties. The spreading of silicon carbide coating layers on carbon fiber surfaces is also one type of effective method. However, oxidation resistant silicon carbide coatings are only capable of protecting fiber surfaces from being oxidized. Once fiber transverse cross sections are exposed to the outside, by contrast, the fibers will rapidly burn and be lost from the core sections, leaving silicon carbide surface layer outer shells behind. Therefore, speaking in terms of antioxidation structural components, it is best to opt for the use of structural design plans with axial fiber directions and perpendicular to the direction of gas flow in order to reduce opportunities for carbon fiber cross sections to be exposed to the outside. Besides this, if ceramic fibers (such as silicon carbide fibers) are used to replace carbon fibers, speaking from the angle of oxidation resistance, it is approved as a possible selection.

(2) Direct Desorption or Deactivation of Catalyzing Impurities [5]

In order to cause catalyzing impurities to be directly desorbed or deactivated, people have made attempts to utilize purified atomic energy graphite technology in order to inhibit oxidation. However, the results certainly did not meet people's expectations.

(3) Binding with Oxidation Inhibitors

One section of research personnel took such oxidation inhibitors as P compounds and bound them to pitch [6] and the inside of fibers [7]. Another section of research personnel took Zr and Ti compounds and directly bound them to graphite and the inside of C/C composite material. However, protection was limited to only under 1000°C.

(4) Total or Partial Displacement of C/C Material Substrate

This seems to be the most successful among what are called interior methods. It is nothing else than using oxygen, organic silicide, and organic titanium compound infiltration technology to cause the carbon substrate in C/C composite materials to be partially or wholly displaced by SiC and TiC [8]. Besides this, a number of antioxidation components are added to substrate carbon--for example, heavy metal compounds (such as tantalum and niobium compounds) and ceramic powders (such as silicon dioxide, silicon carbide, and silicon nitride). Although this is capable of raising the antioxidation properties of carbon substrate, it still, however, very greatly reduces the shear strength between C/C film layers. This is disadvantageous for use. At the present time, what is getting the most research is manufacturing carbon fibers strengthened with silicon carbide (C/SiC) or the use of silicon carbide infiltrated porous C/C base material (C/C-SiC). In this way, substrates are silicon carbide or substrates containing large amounts of silicon carbide and are capable of

raising substrate antioxidation properties.

(5) C/C Carbon Composite Material Autoprotective Methods [9]

As is shown in Fig.2, during the manufacture of C/C composite materials, first of all, use is made of resin substrate to impregnate fiber bundles, forming pre-immersed or preimpregnated materials. After that, on pre-immersed materials, boron carbide is sprinkled. Subsequently, the various layers are taken and congruently hot pressed. Finally, on premolded body surfaces, silicon carbide is spread followed by conversions to carbon and graphite.

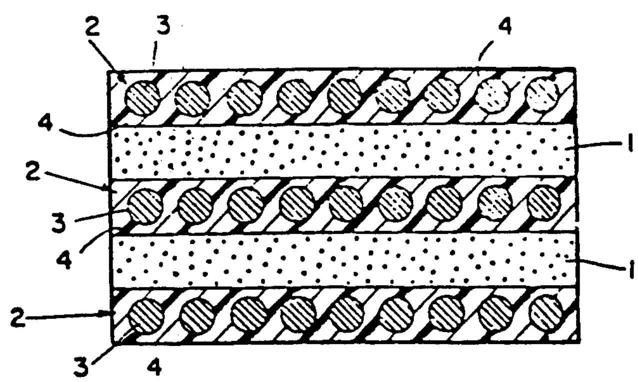

Fig.2 C/C Composite Material Autoprotective Mechanism
Key: (1) Boron Carbide Granules (2) Multiple Unit Carbon or Graphite Fiber Layering (3) Fibers (4) Resin Substrate

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When the premolded body described above is heated to 2000-2300°C, boron carbide diffuses everywhere on composite materials. It acts with silicon carbide to produce boron silicate glass. This type of glass possesses very low viscosity, its fluidity is good, and is capable of healing composite material cracks produced in oxidation processes. However, this type of

protection method is limited only to temperatures below 1200°C. Exceeding this temperature, boron silicate is volatile and loses protective functions.

2. Exterior Protective Methods

In recent years, among general methods associated with covering C/C composite materials with protective layers, there have been [10]: impregnation and spray drenching methods, Silmor technology, chemical vapor deposits, packing or wrapping technology, sol-gel methods, plasma sprays, and so on.

(1) Impregnation and Spray Drenching Methods

Most of the operations associated with impregnation methods are all studied as effects given rise to by boron compounds inhibiting carbon material oxidation. As far as the low melting point of boron glass (approximately 500°C) is concerned, the ability to achieve the wetting of carbon surfaces is, in all cases, the key cause for the relatively good protective results obtained. However, the protective effects of boron glass covering layers will drop under the influence of moisture picked up. Besides this, relatively high evaporation temperatures (approximately 1100°C) limit its use at higher temperatures. With regard to spray drenching methods, a large class of compounds has already been used on C/C materials. However, results are only limited to utilization at approximately 800-1000°C.

(2) Silmor Technology [10]

This type of technology requires taking covered parts and placing them in a 1800°C effector. Above Si and SiO_2, at this temperature, after reactions between the SiO atmosphere formed and carbon surfaces, SiC is created. With regard to a comparison

between this transformation layer and the SiC covering layers produced by other methods, in an ignition environment, during use, it is not easy to peel off.

(3) Packing or Wrapping Technology

The covering layers which are produced by various types of packing and wrapping technologies are capable of supplying the maximum oxidation resistance for carbon materials. In this type of method, there is one most basic technology, that is, packing or wrapping SiC coating layers. The basic technology and forming mechanisms are as follows. Take a mixture of powders such as silicon carbide, silicon, and aluminum oxide and fill up the peripheries of C/C substrate material samples in crucibles. After that, take the crucibles and put them into a high temperature furnace and heat. When the crucible temperature exceeds a certain temperature, the mixed powders will give rise to a liquid phase with the sample surfaces and gas phase reactions will form diffusion coating layers. This diffusion coating layer is nothing else than SiC. The formation mechanisms of SiC coating layers associated with packing or wrapping technologies are quite complicated. However, speaking in general, coating layers have been recognized to be divided into two phases in their formation. First of all are liquid phase reaction processes. Liquid Si and basic C material form SiC. After this, gas phases infiltrate toward inner material layers. In conjunction with this, Si vapor reacts with inner layer material to form SiC. Protective layers formed by this type of method have already been successfully applied to inhibiting the oxidation of space shuttle entry side C/C materials. However, the drawback to coating layers formed by this type of method is that, in cooling processes, layer interiors produce micro cracks. The method for resolving this is the ability, through impregnating the compounds below, to use them as fillers: tetraethylphosphates or alkaline silicates such as SiC, ZrO_2, or

Si_3N_4 and mixtures composed of these high melting point compounds.

(4) Chemical Vapor Deposits

Using chemical vapor deposit methods to grow protective films is one of the most important protective methods for C/C composite materials. The key advantage to CVD methods is that, at relatively low temperatures, it is possible to deposit coating layers associated with various types of elements and compounds. At the same time, using this type of method, it is both possible to obtain glass state substances as well as being able to get coating layers associated with complete and high purity crystal substances. Besides this, as far as coating layers obtained using this type of method are concerned, the chemical constituents and coating layer structures can be accurately controlled. This point is one with which other methods cannot compare.

At the present time, making use of CVD methods, key among protective coating layers grown on C/C composite material surfaces are SiC, Si_3N_4, BN, ZrC, TiC, and so on. Among these, silicon substance coating layers such as SiC, Si_3N_4, etc., are the most widespread.

The general process associated with the depositing of SiC coating layers is: current carrying gases (H_2, Ar, He, N_2) pass through a container filled with trichloromethylesther silicane, methane, silicane, and ethane. After that, they go into a depositing furnace filled with C/C samples. Depositing temperature is generally 1000°C - 1700°C. Depositing chamber pressure and depositing time are controled. It is possible to obtain different structures (for example, crystal state and noncrystal state SiC) and thicknesses of SiC coating layers.

(5) Sol-Gel Methods [11]

Opting for the use of types of ester compounds and metallic alcohol salts to be raw materials in order to prepare nonorganic solid materials is one type of chemical hydrometallurgy. It has been designated as the Sol-Gel method.

As far as using sol-gel methods to form coating layers on C/C composite material surfaces is concerned, it requires that coating layer materials be able to wet C/C base materials, have a certain viscosity and fluidity, and uniformly solidify on substrate surfaces. In conjunction with this, it must be possible to use chemical and physical methods in mutual binding. Coating layers obtained from sol-gel methods come from taking C/C substrate and immersing it in sol. After that, liquid surfaces are raised up in the air and hydrolyzed. Subsequently, they go through drying and are sintered down to the substrate surface. Film thickness is determined by sol viscosity, the speed with which substrate material is lifted back up after immersion, as well as the number of iterations of repeated immersion.

Making use of $Si(OC_2H_5)_4$ and $Zr(OC_2H_5)_4$ as key raw materials, it is possible to make SiO_2 and ZrO_2--SiO_2 glass thin film coating layers. Sim attempted to use sol formed from Al_2O_3 and ZrO_2 on C/C composite materials to obtain ceramic covering layers. Samples were immersed and coated several times, forming a continuous compact covering layer. However, the protective results certainly did not inspire people.

(6) Plasma Spray Methods

With regard to plasma spray methods, in reality, it is possible to make all fire resistant materials capable of obtaining coating layers. James W. Patten, et al, used such oxide compound ceramics as ZrO_2 to spray protective layers on the

outside surfaces of C/C composite materials. According to reports, it is possible, at over 1800°C, to give rise to oxide protection effects with regard to C/C composite materials. Besides this, the authors of the article in question also tested the use of plasma spray methods, spraying such oxide compound ceramic protection layers as ZrO_2, SiO_2, Ta_2O_5, and so on, on C/C composite material surfaces. However, research discovered that, due to very great relative differences of thermal expansion coefficients between coating layers and substrates--besides, in spraying processes, in coating layers, there being small amounts existing of residual gases such as N_2 and Ar--they are the cracking sources associated with the coating layers in question during high temperature use. Because of this, this type of method awaits further exploration and research.

IV. CARBON/CARBON COMPOSITE MATERIAL COATING DESIGN

Due to C/C composite materials possessing low thermal expansion coefficients, in the case of protective layers that are used at the present time, it goes without saying that they are ceramic coating layers associated with such silicon substances as SiC, SiN_4, SiO_2, and so on. They are also other oxide ceramics such as ZrO_2, Ta_2O_5, etc. The thermal expansion coefficients and elasticity moduli are all not able to match up with C/C materials. Because of this, it is necessary to solve the problems of C/C composite material oxide protection. The authors of the article in question recognize that, first of all, it is necessary, on substrates, to add in such glass additives as B_2O_3 to raise the autoprotective properties of substrates themselves. Besides this, the outer coating layers should adopt transitional coatings of multiple layers with different expansion coefficients as shown in Fig.3 [12]. The outer coating layers can be SiC and Si_3N_4 obtained from the use of CVD methods, diffusion reactions, and silmor technology. After that, SiO_2 is impregnated into

surfaces, in order to seal micro cracks in SiC and Si_3N_4 covering layers, so as to achieve optimum antioxidation results.

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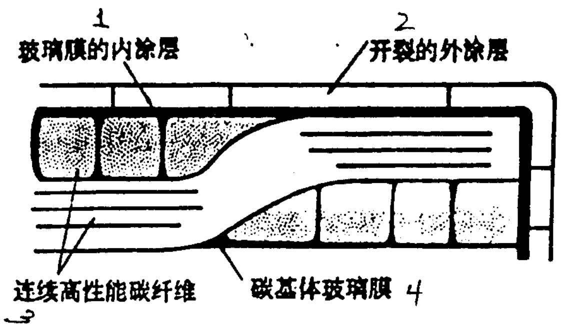

Fig.3 C/C Composite Material Oxidation Protection System

Key: (1) Glass Film Inner Coating Layer (2) Cracked Outer Coating Layer (3) Continuous High Performance Carbon Fibers (4) Carbon Substrate Glass Film

Finally, it is necessary to point out that, in the case of opting for the use of the oxidation protection system shown in Fig.3, the silicon substance ceramic coatings SiC, Si_3N_4, and SiO_2 associated with the actual protective functions are only capable of use at temperatures lower than 1700°C. As far as C/C composite material antioxidation coatings at above 1700°C are concerned, it is necessary to develop new materials and new paths. At the same time, the authors recognize that the plasma spray oxide ceramics introduced in this article, acting as C/C composite outer coating layers, have hope of bringing oxidation protection problems associated with C/C composite materials above 1700°C to resolution.

V. SUMMARY

(1) If there are no outer protective layers, oxidation of C/C composite materials begins, first of all, from carbon fibers. Carbon substrate (CVD or pitch/asphalt carbon) is more resistant to oxidation than carbon fibers.

(2) With regard to C/C composite materials having coating layers, there is a close relationship between oxidation processes and micro cracks existing in coating layers themselves, coating layer properties, as well as coating layer and substrate boundary surface binding, and other similar factors.

(3) If there are no outer protective layers, even if carbon material has interior protection, the utilization temperatures will be below 1000°C.

(4) For the sake of applications in long term oxidation protection at above 1000°C and cyclical temperature changes, one inclusive glass covering layer multilayer coating system is needed. At the present time, the most successful and widely applied multiple layer system is SiC, Si_3N_4, SiO_2, and boron glass. However, it limits oxidation protection temperatures to below 1700°C.

(5) Methods currently used to inhibit C/C composite material oxidation and compounds used are all very expensive. In order to promote broad application of C/C composite materials in high temperature realms, it is necessary to find oxidation inhibiting methods which are not only inexpensive but also relatively flexible.

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